Chapter 7

Physical and chemical characteristics of hydrogeologic units in the Snake-Salt River Basin

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The physical and chemical characteristics of hydrogeologic units in the Snake River Basin (Snake/Salt River Basin) are described in this chapter of the report. For descriptive and summary purposes, wells from which physical and chemical characteristics were obtained were grouped and summarized using six broad "geographic regions" shown in **figures 7-1** and **7-2**. The Gros Ventre, Teton, and Washakie Ranges are combined in one of the six broad geographic regions (the Northern Ranges) and the Green River and Hoback Basins are combined into one of six broad geographic regions (Green River and Hoback Basins) described below, but are shown separately on **figures 7-1** and **7-2**. The Absaroka, Wind River Basin, and Wind River Mountain geographic areas also are shown on **figures 7-1** and **7-2**, but are not included in the six broad geographic regions because no groundwater-quality data were available for the Absaroka and Wind River Basin geographic areas, and the Wind River Mountain geographic area was outside the Snake/Salt River Basin. The six geographic regions were based primarily on the areal extent of structural and geographic features listed below. The areal extent of these structural and geographic features generally follows the approximate areal extents shown in the statewide Phanerozoic stratigraphic nomenclature chart of Love and others (1993, fig. 1); however, the areal extent of some regions also was refined using drainage areas (using 8-digit hydrologic unit codes). The six regions generally include the following geologic structures and associated geographic areas.

Yellowstone Volcanic Area:

- Madison Plateau
- Pitchstone Plateau
- Red Mountains
- Falls River Basin/Cascade Corner

Northern Ranges:

- Teton Range
- Washakie Range
- Gros Ventre Rang

Jackson Hole:

- Jackson Hole

Green River and Hoback Basins:

- Northernmost Green River Basin
- Hoback Basin

Overthrust Belt:

- Snake River Range
- Wyoming Range
- Salt River Range
- Gannett Hills

Star Valley:

- Star Valley

Lithostratigraphic and corresponding hydrostratigraphic (hydrogeologic) units in the Snake/Salt River Basin are shown on **plates 4**, **5**, and **6**. Lithostratigraphic units for specific structural areas identified on these plates were taken directly from the statewide Phanerozoic stratigraphic nomenclature chart of Love and others (1993).

For this report, previously published data describing the physical characteristics of hydrogeologic units (aquifers and confining units) are summarized in tabular format (**pl. 3**). The original sources of the data used to construct the summary are listed at the bottom of the plate. Physical characteristics are summarized to provide a broad summary of hydrogeologic unit characteristics and include spring discharge, well yield, specific capacity, transmissivity, porosity, hydraulic conductivity, and storage (storativity/storage coefficient). Individual data values and corresponding interpretation were utilized and summarized as presented in the original reports—no reinterpretation of existing hydraulic data was conducted for this study. For example, values of transmissivity derived from aquifer tests were used as published in the original reports, and no reanalysis of previously published aquifer tests was conducted. Existing hydraulic data were converted

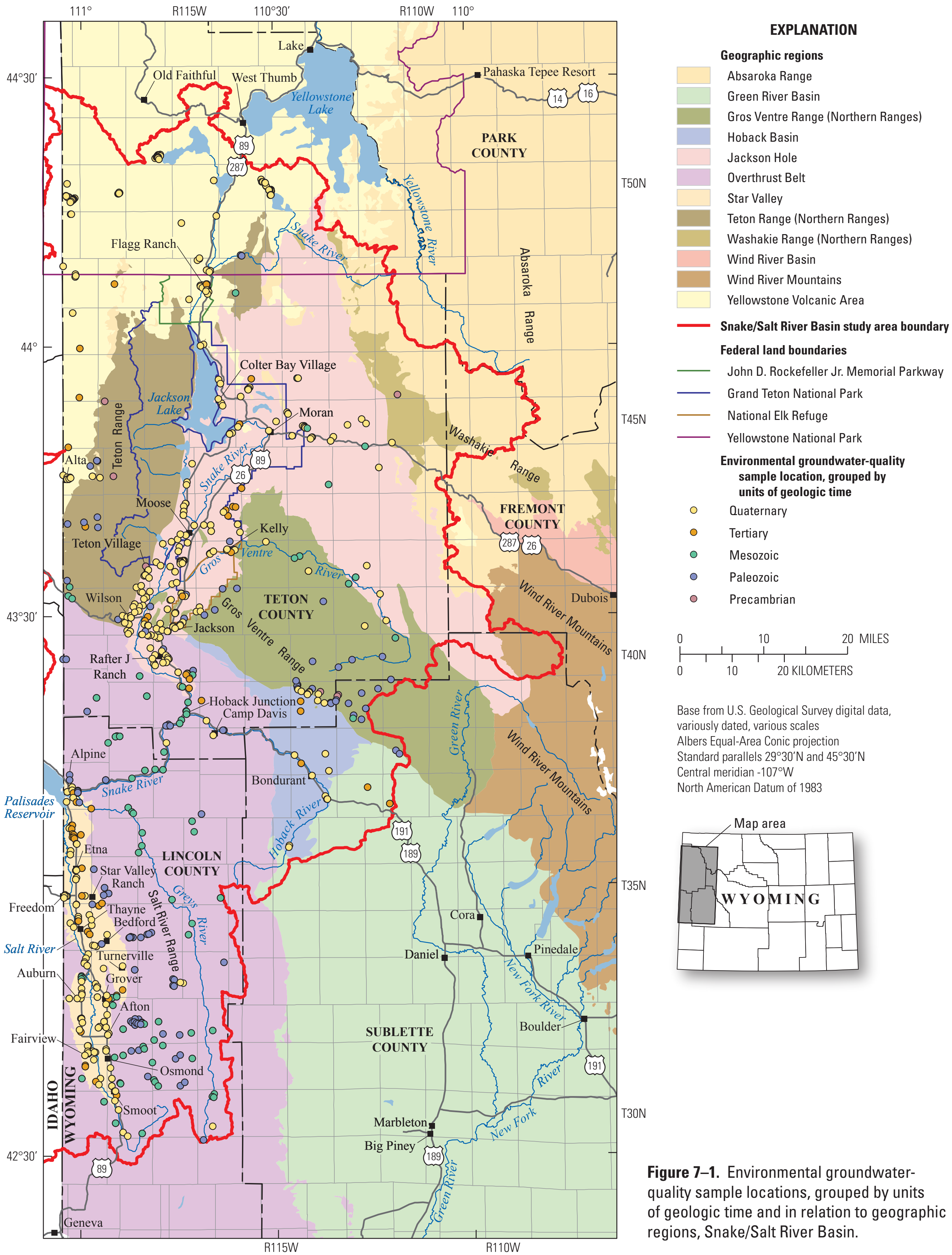
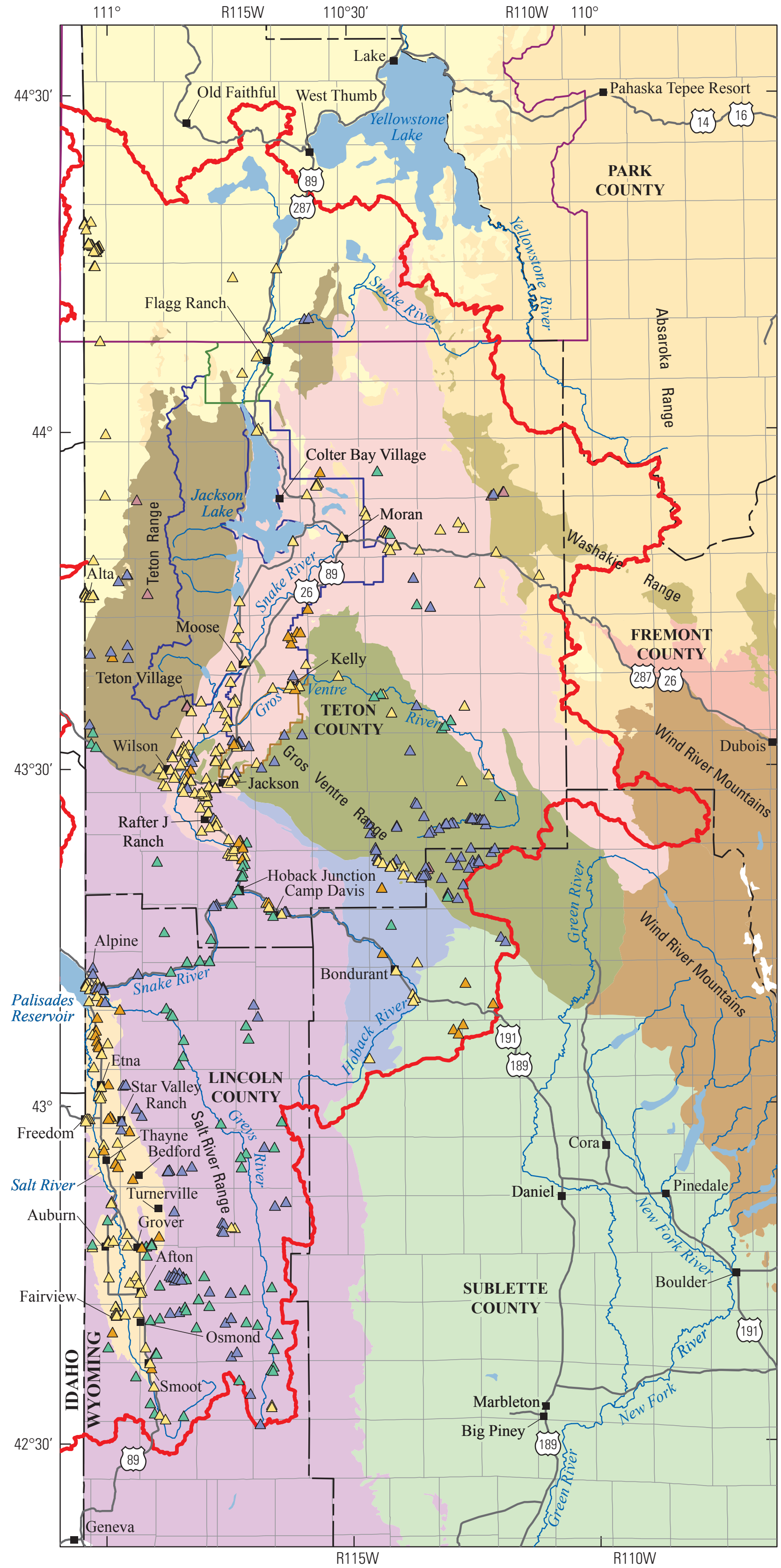


Figure 7–1. Environmental groundwater-quality sample locations, grouped by units of geologic time and in relation to geographic regions, Snake/Salt River Basin.



EXPLANATION

Geographic regions

- Absaroka Range
- Green River Basin
- Gros Ventre Range (Northern Ranges)
- Hoback Basin
- Jackson Hole
- Overthrust Belt
- Star Valley
- Teton Range (Northern Ranges)
- Washakie Range (Northern Ranges)
- Wind River Basin
- Wind River Mountains
- Yellowstone Volcanic Area

Snake/Salt River Basin study area boundary

Federal land boundaries

- John D. Rockefeller Jr. Memorial Parkway
- Grand Teton National Park
- National Elk Refuge
- Yellowstone National Park

Location of springs and wells with physical characteristic information, grouped by units of geologic time

- Quaternary
- Tertiary
- Mesozoic
- Paleozoic
- Precambrian

0 10 20 MILES
0 10 20 KILOMETERS

Base from U.S. Geological Survey digital data, variously dated, various scales
Albers Equal-Area Conic projection
Standard parallels 29°30′N and 45°30′N
Central meridian -107°W
North American Datum of 1983

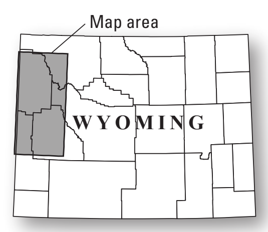


Figure 7–2. Locations of springs and wells with physical characteristic information, grouped by units of geologic time and in relation to geographic regions, Snake/Salt River Basin.

to consistent units to improve readability and facilitate comparability between different studies.

7.1 Snake/Salt River Basin

The physical and chemical characteristics of hydrogeologic units of Cenozoic, Mesozoic, Paleozoic, and Precambrian age in the Snake/Salt River Basin are described in this section of the report. Hydrogeologic units of the Snake/Salt River Basin are identified on **plates 4, 5,** and **6**. The areal extent of hydrogeologic units in the Snake/Salt River Basin is shown on **plate 2**. Many physical characteristic descriptions were modified from Bartos and Hallberg (2010), Clarey (2011), and Bartos and others (2012, 2014).

7.2 Cenozoic hydrogeologic units

Hydrogeologic units of Cenozoic (Quaternary and Tertiary) age are described in this section the report. Cenozoic hydrogeologic units are composed of both unconsolidated deposits such as sand and gravel (primarily of Quaternary age) and consolidated sediments (bedrock of Tertiary age) such as sandstone and conglomerate. Compared with aquifers of Mesozoic, Paleozoic, and Precambrian age, Cenozoic aquifers are the most used sources of groundwater. Cenozoic aquifers are used as a source of water for stock, domestic, industrial, irrigation, and public-supply purposes in the Snake/Salt River Basin.

7.2.1 Quaternary unconsolidated deposits

Where saturated and sufficiently permeable, unconsolidated sediments of Quaternary age in the Snake/Salt River Basin can contain aquifers. Saturated Quaternary unconsolidated deposits that contain aquifers (referred to herein as “Quaternary unconsolidated-deposit aquifers”) in the Snake/Salt River Basin typically include alluvium and colluvium (identified herein as "Quaternary alluvial aquifers"), terrace deposits (identified herein as "Quaternary terrace-deposit aquifers"), and glacial deposits (identified herein as "Quaternary glacial-deposit aquifers"). These aquifers can be highly productive locally and are the source of water for many shallow wells in the Snake/Salt River Basin. Quaternary unconsolidated-deposit aquifers are the most used sources of groundwater in the Snake/Salt River Basin for stock, domestic, industrial, irrigation, and public-supply purposes. The largest use of these aquifers occurs in the Snake River valley and the Salt River valley (also known as the Star Valley); both valleys coincide with much of the rural and urban population in the study area.

The physical and chemical characteristics of saturated Quaternary unconsolidated-deposits aquifers in the Snake/Salt River Basin are described in this section of the report.

In addition, a previously constructed groundwater-flow model of a Quaternary unconsolidated-deposit aquifer in the Snake/Salt River Basin is identified and briefly described.

Physical characteristics

Quaternary unconsolidated deposits are composed primarily of sand and gravel interbedded with finer-grained sediments such as silt and clay, although coarser deposits such as cobbles and boulders occur locally (Lines and Glass, 1975; Cox, 1976; Ahern and others, 1981; Love and others, 1992; Sunrise Engineering, 2003, 2009). In places, unconsolidated deposits of Quaternary age are intermixed with unconsolidated deposits of Tertiary age (for example, Love, 2001a, b, c). Several types of unconsolidated deposits of Quaternary age are present in the Snake/Salt River Basin (**pls. 1** and **2**). Collectively, the Quaternary unconsolidated deposits can be thought of as "valley fill" or "basin fill" because the deposits partly fill many of the narrow and broad river valleys of the Snake/Salt River Basin formed by faulting, erosion, or both, through which the Snake and Salt Rivers and related tributaries flow. The deposits commonly grade into and (or) overlie one another and are bounded laterally or vertically by (rest on top of) bedrock. The size of sediments composing the deposits is related primarily to the source of the eroded and transported parent material and the distance the sediments have been transported.

Estimates of the maximum thickness of Quaternary unconsolidated deposits are uncommon for many areas in the Snake/Salt River Basin and available estimates vary substantially by location, primarily because few wells in most areas fully penetrate the deposits. Behrendt and others (1968) estimated that Holocene deposits (less than 10,000 years before present) are as thick as 400 feet (ft) in the Jackson Hole area. North of the Overthrust Belt, Cox (1976, Sheet 1) estimated that the maximum thickness of alluvium, terrace deposits, and glacial outwash deposits was about 200 ft. Lines and Glass (1975, Sheet 1) noted that wells completed in Quaternary alluvial deposits (composed of flood-plain alluvium and alluvial fans) in the Overthrust Belt generally were less than 200 ft in depth, and thus, the maximum thickness was unknown. Because thicknesses vary substantially by location, individual geologic maps should be consulted to determine thickness ranges for Quaternary unconsolidated deposits in areas of interest in the Snake/Salt River Basin.

Quaternary-age alluvium is composed of unconsolidated, poorly to well sorted mixtures of clay, silt, sand, and gravel deposited along streams, primarily as channel-fill and flood-plain deposits. Locally, alluvium can include alluvial fan and terrace deposits, valley side colluvium or talus, reworked glacial outwash deposits, and sediments deposited in small bogs, lakes, or deltas. Alluvium commonly grades laterally and vertically into other adjacent Quaternary unconsolidated deposits, typically terrace deposits; consequently, it is often difficult to determine where to differentiate the different types of Quaternary unconsolidated deposits in the Snake/Salt River Basin. In addition, different investigators have not always been consistent when mapping/identifying ("lumping and splitting") the different types of Quaternary unconsolidated deposits. Furthermore, use of different scale geologic maps results in different groupings of the unconsolidated deposits.

Quaternary unconsolidated terrace deposits (also described as gravel, pediment, and fan deposits, terrace gravel deposits, or terrace, gravel, and fan deposits) are present in the Snake/Salt River Basin, primarily adjacent to the alluvium in river valleys (**pls. 1** and **2**). Like alluvium, terrace deposits are composed of unconsolidated sand and gravel, and less commonly of cobbles and boulders derived from older sedimentary and crystalline rocks; stratification and sorting varies, and coarser sediments commonly are interbedded/intermixed with finer-grained sediments such as clay and silt. The size of sediments composing the deposits is related primarily to the source of the eroded parent material and distance transported. The areal extent of terrace deposits generally is small, and the deposits typically are found along uplands bordering principal streams of the Snake/Salt River Basin (**pls. 1** and **2**); however, areally extensive deposits are found in some areas, most notably in Jackson Hole and Star Valley (**pls. 1** and **2**). Terrace deposits may be present in many different terrace levels alongside streams draining the basin and in adjacent upland areas. Terrace-deposit thickness varies substantially in the Snake/Salt River Basin and depends on stream or river valley association and location.

Colluvium is composed of unconsolidated and poorly sorted sediment ranging in size from silt to boulder-sized rocks mantling major stream valley sides, tributary stream valleys, and the bases of hillsides/hillslopes (Love and others, 1992). Colluvium generally is deposited by rainwash, sheet wash, or slow continuous downslope creep (Bates and Jackson, 1980). Locally, colluvium can include soil, gravel, and glacial drift. Colluvium commonly is included (mapped) with alluvium on geologic maps of the Snake/Salt River Basin. Colluvium, composed of poorly sorted debris at the base of steep slopes or slope wash, is included with alluvium in this report for summary purposes.

Quaternary alluvial fan deposits occur along the river valleys in the Snake/Salt River Basin (Love and others, 1992). The alluvial fan deposits are composed of unconsolidated, poorly sorted, alluvium and colluvium forming well defined fan-shaped deposits at mouths of tributary valleys. Like colluvium, Quaternary alluvial fan deposits commonly are included (mapped) with alluvium on geologic maps of the Snake/Salt River Basin.

Glaciation has affected many parts of the Snake/Salt River Basin. Sediments deposited during glaciation (Quaternary glacial deposits) generally are till and moraine or outwash deposits, consisting of unconsolidated, unstratified to stratified, sorted to unsorted mixtures of rock fragments (including boulders), gravel, sand, silt, and clay deposited by alpine (mountain) glaciers (Love and others, 1992). Glacial till and moraine deposits are deposited directly by and underneath glaciers without subsequent reworking by meltwater (Bates and Jackson, 1980). Glacial outwash deposits are transported from glaciers by meltwater streams and deposited in front of or beyond the end moraine or the margin of an active glacier (Bates and Jackson, 1980). Quaternary glacial deposits may be considered aquifers and developed where sufficiently water saturated and permeable. Productive wells completed in glacial deposits in the Snake/Salt River Basin likely are completed in outwash deposits composed of permeable, stratified coarse sand and gravel because deposits comprising tills and moraines generally are much less permeable because of lack of stratification, poor sorting, and fine grain size (Whitehead, 1996).

Where saturated and permeable, Quaternary unconsolidated deposits can contain aquifers. Quaternary unconsolidated-deposit aquifers are small in areal extent and primarily occur in alluvium (commonly associated with colluvium and referred to herein as "alluvial aquifers"), terrace deposits (sometimes referred to as "terrace gravel deposits" or "terrace, gravel, and fan deposits" in some reports and referred to herein as "terrace-deposit aquifers") and glacial deposits (referred to herein as "glacial-deposit aquifers") along stream and river valleys and in adjacent upland areas in the Snake/Salt River Basin (**pls. 1** and **2**).

Although limited in areal extent, Quaternary unconsolidated-deposit aquifers (most commonly alluvial and terrace-deposit aquifers) are the most used and some of the most productive aquifers in the Snake/Salt River Basin (Lines and Glass, 1975; Cox, 1976; Ahern and others, 1981; Sunrise Engineering, 2003, 2009, and references therein). Much of the population in the Snake/Salt River Basin coincides with and directly overlies the Quaternary alluvial and terrace-deposit aquifers. Consequently, most wells completed in Quaternary unconsolidated-deposit aquifers are located close to and along streams and rivers, most commonly along parts of the Salt River (Star Valley) and the Snake River valley and associated tributaries (WSGS needs to add proper figure/map reference from earlier chapter here). Most irrigated lands in the Snake/Salt River Basin overlie Quaternary unconsolidated-deposit aquifers (Sunrise Engineering, 2003, Figures II-1 and II-2).

Groundwater in Quaternary unconsolidated-deposit aquifers in the Snake/Salt River Basin typically is unconfined (water-table conditions predominate). However, fine-grained sediments overlying coarse-grained permeable zones can result in locally confined conditions or overlying perched water tables at some locations in the Snake/Salt River Basin (for example, Walker, 1965).

Along the flood plains and stream valleys, aquifers in alluvium and associated terrace deposits typically are in hydraulic connection with one another and adjacent streams and rivers (Walker, 1965; Lines and Glass, 1975, Sheet 1; Hinckley Consulting and Jorgensen Engineering, 1994; Eddy-Miller and others, 1996, 2009, 2013b; Wyoming State Engineer's Office, 1995, 2005; Wheeler and Eddy-Miller, 2005;. In addition, Quaternary alluvial and terrace-deposit aquifers are in hydraulic connection with adjacent or underlying Tertiary bedrock aquifers at some locations.

An unconsolidated-deposit aquifer primarily composed of Quaternary alluvium and terrace deposits and limited glacial deposits, referred to herein as the Snake River alluvial aquifer, underlies much of the Jackson Hole area (Cox, 1976, Plate 3; Nolan and Miller, 1995; San Juan and Kolm, 1996; Nolan and others, 1998). The areal extent and generalized potentiometric surface of the aquifer are shown on **figure 7-3**. Nolan and Miller (1995) and Nolan and others (1998) informally named this aquifer the "Jackson aquifer." This aquifer provides much of the water used for stock, domestic, irrigation, industrial, and public-supply purposes in the area. Saturated aquifer thickness was estimated by Cox (1976, plate 3) to range from less than 50 ft to as much as 300 ft. Using a time-domain electromagnetic survey conducted mostly

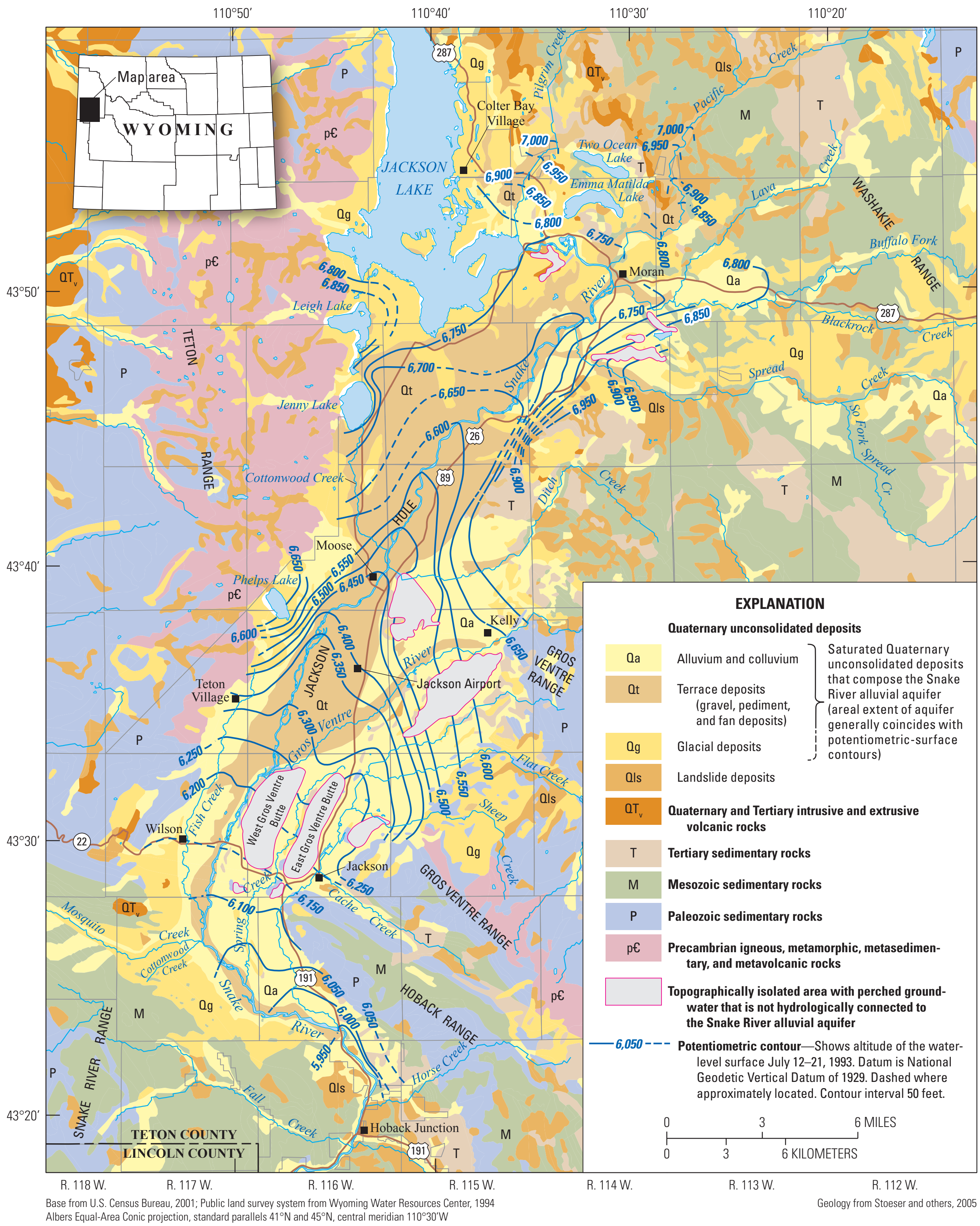


Figure 7–3. Areal extent and generalized potentiometric surface of the Snake River alluvial aquifer, Jackson Hole, Wyoming, July 12–21, 1993 (modified from Nolan and Miller, 1995, Plate 3).

in Grand Teton National Park, Nolan and Miller (1995) estimated that the depth of Quaternary unconsolidated deposits at nine locations within the areal extent of the aquifer ranged from about 380 to 2,400 ft. Using audio-magnetotellurics (a deep exploration electromagnetic method), Nolan and others (1998) estimated depth of the base of the aquifer for the southern part of the aquifer (area from about 4.5 miles north of Hoback Junction to less than 1 mile north of Teton Village). Estimated depth of the base of the aquifer for this area ranged from about 100 ft in the south, near the confluences of Spring Creek and Flat Creek with the Snake River, to about 700 ft in the west, near the town of Wilson, Wyoming; median depth of the base of the aquifer was estimated to be about 200 ft. Much of the aquifer is underlain by Quaternary unconsolidated lacustrine deposits and other finer grained, less permeable lithostratigraphic units (Cox, 1976, pl. 3; Nolan and Miller, 1995; Nolan and others, 1998).

Quaternary loess deposits, also defined as eolian deposits in some publications, consist of wind-blown, light gray, unconsolidated silt (Love and Albee, 1972). Saturated, loess deposits typically yield very small volumes of groundwater because of predominantly fine grain size. In some parts of the Snake/Salt River Basin, Quaternary loess deposits are intermixed with Quaternary lithified talus deposits. Quaternary lithified talus deposits (breccias) are composed of angular Paleozoic rock fragments (primarily eroded from the Madison Limestone) cemented by a white limey cement (Love and Albee, 1972). Locally, saturated loess and lithified talus deposits in the Snake/Salt River Basin may be sufficiently saturated and permeable to yield water to wells, as several wells likely completed in these deposits were inventoried as part of this study (**pl. 3**).

Quaternary landslide deposits are composed of masses of soil, sediment, and older bedrock that have moved downward under gravity and accumulated at the base of hillsides and steep slopes (Love and others, 1992; Love and Reed, 2000; Love and Albee, 1972). Quaternary landslide deposits in the Snake/Salt River Basin (**pls. 1** and **2**) are saturated at some locations. Lines and Glass (1975, Sheet 1) noted that landslide deposits (identified as "rock debris") in the Overthrust Belt likely were not a potential source of water because of poor sediment sorting and small saturated thickness. Cox (1976, Sheet 1) noted that wells completed in these deposits probably would not yield more than a few gallons per minute. Only one well completed in Quaternary landslide deposits was inventoried as part of this study, but springs commonly issue from the base of the Quaternary landslide deposits in the study area.

Hydrogeologic data describing the Quaternary unconsolidated deposits in the Snake/Salt River Basin (alluvial aquifers, terrace-deposit aquifers, glacial-deposit aquifers, landslide deposits, and loess deposits), including spring-discharge and well-yield measurements, and other hydraulic properties, are summarized on **plate 3**. Well yields and physical properties of Quaternary unconsolidated-deposit aquifers are highly variable (**pl. 3**), reflecting the variable size, sorting, and stratification of sediments comprising the deposits, as well as saturated thickness that changes in response to different amounts of aquifer recharge and discharge (water withdrawal). In some areas of the Snake/Salt River Basin, most notably in alluvium and terrace deposits of the Jackson Hole area (part of the Snake River alluvial aquifer), well yields, specific capacities, and conductivities/transmissivities are high because of large saturated thicknesses and coarse-grained deposits.

Because the areal extent of Quaternary unconsolidated-deposit aquifers coincides with most of the population and irrigated cropland in the Snake/Salt River Basin, these aquifers particularly are susceptible to effects from human activities (Hamerlinck and Arneson, 1998). Evidence of localized effects to groundwater quality in Quaternary unconsolidated-deposit aquifers by human activities in the Snake/Salt River Basin has been indicated by detection of elevated nitrate concentrations, as well as by low-level detections of organic compounds such as pesticides (Eddy-Miller and others, 1996; Eddy-Miller and Norris, 2000; Eddy-Miller and Remley, 2004; Sunrise Engineering, 2009; Eddy-Miller and others, 2013a). Hedmark and Young (1999) documented groundwater-quality degradation from disposal of wastewater into sewage lagoons overlying Quaternary unconsolidated-deposit aquifers used to supply water for different uses in Grand Teton National Park and the John D. Rockefeller Memorial Parkway. Anti-icing/deicing compounds were found in the Snake River alluvial aquifer near the Jackson Hole Airport (Wright, 2013).

Recharge, discharge, and groundwater movement

Recharge to Quaternary unconsolidated-deposit aquifers primarily is from direct infiltration of precipitation (snowmelt and rain), snowmelt runoff, lakes, and ephemeral and perennial streamflow losses (Walker, 1965; Lines and Glass, 1975, Sheet 1; Cox, 1976; Ahern and others, 1981; Nelson Engineering, 1992; Wyoming State Engineer's Office, 1995, 2005; Hinckley Consulting and Jorgensen Engineering, 1994; Wheeler and Eddy-Miller, 2005; Eddy-Miller and others, 2009, 2013b; Wright, 2010, 2013). Infiltration of diverted surface water through unlined irrigation canals and ditches, from water applied to fields using flood and sprinkler irrigation, and discharge from adjacent and underlying bedrock aquifers also provide recharge in some areas (Walker, 1965; Lines and Glass, 1975, Sheet 1; Ahern and others, 1981; Sando and others, 1985; Hinckley Consulting and Jorgensen Engineering, 1994; Wyoming State Engineer's Office, 1995, 2005). In areas coinciding with population, additional recharge may occur from localized lawn watering, septic leach fields, and wastewater injection wells (Hinckley Consulting and Jorgensen Engineering, 1994). Most recharge occurs in the spring as a result of infiltration and percolation of rainfall, snowmelt, and snowmelt runoff (Walker, 1965; Lines and Glass, 1975, Sheet 1; Nelson Engineering, 1992; Hinckley Consulting and Jorgensen Engineering, 1994; Hedmark and Young, 1999; Wyoming State Engineer's Office, 1995, 2005; Eddy-Miller and others, 2009, 2013b; Wright, 2010, 2013). Some of the recharge to Quaternary unconsolidated-deposit aquifers from streams may occur as water infiltrates the heads of alluvial fans along the margins of stream valleys in the Snake/Salt River Basin (Walker, 1965; Lines and Glass, 1975, Sheet 1).

Water levels in Quaternary unconsolidated deposit aquifers in the Snake/Salt River Basin also can be affected by water-surface elevations in nearby reservoirs. In the Alpine Junction area (includes town of Alpine and adjacent unincorporated lands), groundwater-level fluctuations in the Quaternary unconsolidated deposits or Tertiary Salt Lake Formation in the area (difficult to differentiate these lithostratigraphic units in the subsurface in the vicinity of the town), or both have been correlated to changes in the water-surface elevation of nearby Palisades Reservoir (Sunrise Engineering, 1995).

In irrigated areas, water levels in the Quaternary unconsolidated-deposit aquifers in the Snake/Salt River Basin may increase in response to recharge from seasonal application of diverted surface water through flooding or sprinkler methods used to irrigate crops (Walker, 1965; Lines and Glass, 1975, Sheet 1; Cox, 1976; Ahern and others, 1981; Hinckley Consulting and Jorgensen Engineering, 1994; Wyoming State Engineer's Office, 1995). Water levels in some wells completed in Quaternary unconsolidated-deposit aquifers in Star Valley may be highest (shallowest) during the growing season when irrigation water recharges the aquifers, and water levels may be lowest (deepest) after irrigation has ceased during the winter when water is discharged from the aquifers (Walker, 1965).

Because of ongoing concerns about high (shallow) groundwater levels in the Snake River alluvial aquifer east of Fish Creek and west of the Snake River (area known as the west bank of the Snake River or Snake River west bank), the effects of potential recharge from residential ponds to the aquifer was investigated by Hinckley Consulting and Jorgensen Engineering (1994). Residential ponds are constructed into unconsolidated deposits composing the Snake River alluvial aquifer in this area to "enhance aesthetics, provide seasonal fisheries, create wildlife habitat, and provide recreational use" (Hinckley Consulting and Jorgensen Engineering, 1994, pl. 1). Study findings indicated that the ponds had little effect on surrounding groundwater levels relative to the substantially larger normal seasonal and annual groundwater-level fluctuations measured in the aquifer (Hinckley Consulting and Jorgensen Engineering, 1994).

Discharge from Quaternary unconsolidated-deposit aquifers occurs from withdrawals by pumped wells and naturally by evapotranspiration, gaining streams, seeps, and spring flows (Walker, 1965; Lines and Glass, 1975, Sheet 1; Cox, 1976; Ahern and others, 1981; Nelson Engineering, 1992; Hinckley Consulting and Jorgensen Engineering, 1994; Wheeler and Eddy-Miller, 2005; Wyoming State Engineer's Office, 2005; Eddy-Miller and others, 2009, 2013b). Evapotranspiration from Quaternary unconsolidated-deposit aquifers is likely to be highest in the summer and in areas where the water table is at or near the land surface, such as in alluvium near streams.

Groundwater flow in the Quaternary alluvial aquifers generally is towards the center of the river or stream valley or generally in a downstream direction paralleling the direction of the surface-water flow in the river or streams, including as underflow parallel to streamflow (Lines and Glass, 1975, Sheet 1; Cox, 1976; Ahern and others, 1981; Nolan and Miller, 1995). In terrace-deposit aquifers, the direction of groundwater flow generally is similar to groundwater flow in Quaternary alluvial aquifers and is toward the principal surface drainage.

Several potentiometric-surface maps have been constructed showing the direction of horizontal groundwater flow in the Snake River alluvial aquifer (composed of saturated Quaternary alluvial, terrace, and glacial deposits along the Snake River and some of the valleys of tributaries to the Snake River; areal extent of aquifer shown in figure 7-3) (Cox, 1976, Sheet 3; Nolan and Miller, 1995) or parts of the aquifer in the Snake River west bank area (Wyoming State Engineer's Office, 2005). The generalized potentiometric-surface map of the Snake River alluvial aquifer in the Jackson Hole area constructed by Nolan and Miller (1995, Plate 3) is reproduced herein as figure 7-3.

Potentiometric-surface contours on the maps constructed by Cox (1976, Sheet 3) and Nolan and Miller (1995, Plate 3; reproduced herein as figure 7-3) show the general direction of regional groundwater flow; site-specific groundwater-flow directions could differ. Groundwater is assumed to flow in a direction perpendicular to the potentiometric-surface contours, from areas of high hydraulic head to areas of low hydraulic head. Groundwater-flow directions are not constant, and flow direction can change during different times of the year. Potentiometric-surface maps by Cox (1976, Sheet 3) and Nolan and Miller (1995, Plate 3, reproduced herein as figure 7-3) show that groundwater in the Snake River alluvial aquifer generally moves from topographically high areas toward the Snake River and southwest through the valley in the direction of the river.

Contours on potentiometric-surface maps in the immediate vicinity of streams can indicate gaining streams by pointing in an upstream direction (potentiometric surface above water in the stream) or losing streams by pointing in a downstream direction (potentiometric surface below water in the stream). General areas of streamflow loss to and gain from the Snake River alluvial aquifer can be visually identified on the maps of Cox (1976, Sheet 3) and Nolan and Miller (1995, Plate 3; reproduced herein as figure 7-3). Because the contours point in an upstream direction, the Snake River generally was gaining water from the aquifer throughout most of the valley at the time groundwater levels were measured to construct the maps (Cox, 1976, Sheet 3; Nolan and Miller, 1995, Plate 3). Cox (1976, Sheets 2, 3) used the contour map, in combination with streamflow loss and gain measurements for selected stream reaches, to determine that the Snake River and Buffalo Fork were gaining streams, Pilgrim and Cottonwood Creeks were losing streams, and the Gros Ventre River was neither gaining nor losing.

The Wyoming State Engineer's Office (2005, Figure 2) constructed a potentiometric-surface map for part of the Snake River alluvial aquifer in the west bank of the Snake River. The map was constructed using water levels measured in June

1998, and shows that groundwater in the west bank area generally moves southwest from the Snake River towards Fish Creek.

Wright (2011, 2013) examined groundwater levels and seasonal groundwater-level fluctuations of the Snake River alluvial aquifer at the Jackson Hole Airport. Large groundwater-level fluctuations associated with infiltration and percolation of spring precipitation and snowmelt were documented in both studies. Potentiometric-surface maps of the Snake River alluvial aquifer were constructed for the airport area as part of both studies.

Groundwater-flow model

A groundwater-flow model of the Snake River alluvial aquifer from Jackson Lake southward to the Snake River Canyon of the Snake River was constructed by San Juan and Kolm (1996). The unconfined aquifer was modeled using two layers, and was constructed using the then-current version of the finite-difference groundwater-flow model MODFLOW (McDonald and Harbaugh, 1988). The investigators used the groundwater-flow model to improve conceptualization and characterization of the aquifer with particular emphasis on using then-current geographic information system data management and analysis tools. Much of the hydrologic data used to construct the model was from Cox (1976). The model was constructed to simulate two-dimensional steady-state conditions, and the investigators concluded that refinement of both the conceptual and numerical models would be necessary to evaluate potential groundwater-management scenarios.

Chemical characteristics

The chemical characteristics of saturated Quaternary unconsolidated deposits in the Snake/Salt River Basin (Quaternary alluvial aquifers, terrace-deposit aquifers, glacial-deposit aquifers, landslide deposits, and loess and lithified talus deposits) are described in this section of the report.

7.2.1.1 Quaternary alluvial aquifers

The chemical characteristics of groundwater from Quaternary alluvial aquifers in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary alluvial aquifers is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2)**, and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–1** to **E–6**).

Yellowstone Volcanic Area
The chemical composition of Quaternary alluvial aquifers in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of environmental water samples from as many as four wells. Summary statistics calculated for available constituents are listed in **appendix E–1**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–1, diagram A**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1; appendix F–1, diagram A**). TDS concentrations ranged from 131 to 248 mg/L, with a median of 147 mg/L.

Concentrations of some properties and constituents in water from Quaternary alluvial aquifers in the YVA approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent exceeded health-based standards: arsenic (both samples exceeded the USEPA MCL of 10 μg/L). Concentrations of several properties and constituents exceeded aesthetic standards (USEPA SMCLs) for domestic use: fluoride (all 4 samples exceeded the SMCL of 2 mg/L) and aluminum (1 of 2 samples exceeded the lower SMCL limit of 50 μg/L and the upper SMCL limit of 200 μg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming agriculture or livestock water-quality standards.

Northern Ranges
The chemical composition of Quaternary alluvial aquifers in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as five wells and one spring. Summary statistics calculated for available constituents are listed in **appendix E–2**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–2, diagram A**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; Appendix F–2, diagram A**). TDS concentrations for the wells ranged from 160 to 267 mg/L, with a median of 233 mg/L. The TDS concentration for the spring was 159 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary alluvial aquifers in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole
The chemical composition of Quaternary alluvial aquifers in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs and 117 wells. Summary statistics calculated for available constituents are listed in **appendix E–3**. Major-ion composition in relation to TDS for water samples collected from wells is shown on a trilinear diagram (**appendix F–3, diagram A**). TDS concentrations were variable and indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagram A**). The TDS concentration for one spring was 470 mg/L. TDS concentrations for the wells ranged from 52.0 to 628 mg/L, with a median of 250 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary alluvial aquifers in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards in the spring samples.

Concentrations of some properties and constituents in water from wells completed in alluvial aquifers in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters from wells were suitable for domestic use, but concentrations of two constituents exceeded USEPA health-based standards: radon (all 11 samples exceeded the proposed MCL of 300 pCi/L, but none exceeded the AMCL of 4,000 pCi/L), and uranium (1 of 2 samples exceeded the MCL of 30 mg/L). Concentrations of several characteristics and constituents exceeded aesthetic standards for domestic use: aluminum (1 of 13 samples exceeded the lower SMCL limit of 50 μg/L and the upper SMCL limit of 200 μg/L), iron (3 of 44 samples exceeded the SMCL of 300 μg/L), manganese (2 of 31 samples exceeded the SMCL of 50 μg/L), TDS (2 of 71 samples exceeded the SMCL of 500 mg/L), fluoride (1 of 71 samples exceeded the SMCL of 2 mg/L), sulfate (1 of 72 samples exceeded the SMCL of 250 mg/L), and pH (1 of 97 samples above upper SMCL limit of 8.5).

Concentrations of some characteristics and constituents in water from wells completed in alluvial aquifers in JH exceeded State of Wyoming standards for agricultural and livestock use. One characteristic and one constituent in environmental water samples from wells were measured at concentrations greater than agricultural-use standards: sulfate (2 of 72 samples exceeded the WDEQ Class II standard of 200 mg/L) and SAR (1 of 68 samples exceeded the WDEQ Class II standard of 8). One characteristic (pH) was measured outside the range for livestock use (1 of 97 samples above upper WDEQ Class III limit of 8.5).

Green River and Hoback Basins
The chemical composition of Quaternary alluvial aquifers in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of environmental water samples from

one spring and as many as eight wells. Summary statistics calculated for available constituents are listed in **appendix E–4**. Major-ion composition in relation to TDS for water samples collected from wells is shown on a trilinear diagram (**appendix F–4, diagram A**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4; appendix F–4, diagram A**). The TDS concentration for the spring was 250 mg/L. TDS concentrations for the wells ranged from 285 to 445 mg/L, with a median of 356 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary alluvial aquifers in the GH was suitable for most uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent (radon) exceeded health-based standards (the 1 sample analyzed for this constituent exceeded the proposed MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L) No State of Wyoming domestic, agriculture, or livestock water-quality standards were exceeded.

Overthrust Belt

The chemical composition of Quaternary alluvial aquifers in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as eight wells. Summary statistics calculated for available constituents are listed in **appendix E–5**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–5, diagram A**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram A**). TDS concentrations for the wells ranged from 230 to 333 mg/L, with a median of 311 mg/L. Most environmental waters were suitable for domestic use, but concentrations of one constituent (radon) exceeded health-based standards (the 1 sample analyzed for this constituent exceeded the proposed MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L) No State of Wyoming domestic, agriculture, or livestock water-quality standards were exceeded.

Star Valley

The chemical composition of Quaternary alluvial aquifers in Star Valley (SV) was characterized and the quality evaluated on the basis of environmental water samples from as many as 83 wells. Summary statistics calculated for available constituents are listed in **appendix E–6**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–6, diagram A**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–6; appendix F–6, diagram A**). TDS concentrations for the wells ranged from 198 to 589 mg/L, with a median of 262 mg/L.

Concentrations of some properties and constituents in water from wells completed in alluvial aquifers in SV approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of some constituents exceeded health-based standards: radon (all 6 samples exceeded the proposed USEPA MCL of 300 pCi/L, but none exceeded the AMCL of 4,000 pCi/L), nitrate (3 of 38 samples exceeded the USEPA MCL of 10 mg/L), and nitrate plus nitrite (3 of 51 samples exceeded the USEPA MCL of 10 mg/L. Concentrations of one constituent and one characteristic exceeded USEPA aesthetic standards for domestic use: iron (1 of 14 samples exceeded the SMCL of 300 μg/L) and TDS (1 of 47 samples exceeded the SMCL of 500 mg/L).

Concentrations of some properties and constituents in water from wells completed in alluvial aquifers in SV exceeded State of Wyoming standards for agricultural and livestock use. One constituent in environmental water samples that had concentrations greater than agricultural-use standards was chloride (2 of 46 samples exceeded the WDEQ Class II standard of 100 mg/L). No characteristics or constituents had concentrations that approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.2.1.2 Quaternary terrace-deposit aquifers

The chemical characteristics of groundwater from Quaternary terrace-deposit aquifers in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary terrace-deposit aquifers is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–1**, **E–2**, **E–3**, **E–5**, and **E–6**).

Yellowstone Volcanic Area

The chemical composition of Quaternary terrace-deposit aquifers in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of environmental water samples from as many as three wells. Individual constituent concentrations for available constituents are listed in **appendix E–1**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–1, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1; appendix F–1, diagram B**). TDS concentrations ranged from 143 to 198 milligrams per liter (mg/L), with a median of 192 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary terrace-deposit aquifers in the YVA was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Northern Ranges

The chemical composition of groundwater in Quaternary terrace-deposit aquifers in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from one spring and two wells. Individual constituent concentrations for available constituents are listed in **appendix E–2**. TDS concentrations measured in water from the spring (172 mg/L) and both wells (173 and 601 mg/L) indicate that the water is fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2**).

On the basis of the characteristics and constituents analyzed for, the quality of water from one spring issuing from Quaternary terrace-deposit aquifers in the NR was suitable for most uses. No characteristics or constituents measured in the spring sample approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some characteristics and constituents in water from wells completed in the Quaternary terrace-deposit aquifers in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent in one of the well samples exceeded USEPA health-based standards: fluoride (MCL of 4 mg/L). Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use in one of two well samples: TDS (SMCL of 500 mg/L) and fluoride (SMCL of 2 mg/L).

Concentrations of some characteristics and constituents in water from wells completed in the Quaternary terrace-deposit aquifers exceeded State of Wyoming standards for agricultural and livestock use in the NR. One characteristic and one constituent in environmental water samples from one of the wells had concentrations greater than agricultural-use standards: SAR (WDEQ Class II standard of 8) and chloride (WDEQ Class II standard of 100 mg/L). No characteristics or constituents had concentrations that approached or exceeded applicable State of Wyoming livestock water-quality standards.

Jackson Hole

The chemical composition of Quaternary terrace-deposit aquifers in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from one spring and as many as 22 wells. Summary statistics calculated for available constituents are listed in **appendix E–3**, and major-ion composition in relation to TDS is shown on a trilinear diagram for the well samples (**appendix F–3, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagram B**). The TDS concentration for the spring was 173 mg/L.TDS concentrations for the wells ranged from 58.0 to 267 mg/L, with a median of 178 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from the one spring issuing from Quaternary terrace-deposit aquifers in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from wells completed in Quaternary terrace-deposit aquifers in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent (radon) exceeded health-based standards (the 1 sample analyzed for this constituent exceeded the proposed MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L). Concentrations of two constituents and one characteristic exceeded USEPA aesthetic standards for domestic use: manganese (6 of 13 samples exceeded the SMCL of 50 μg/L), iron (3 of 16 samples exceeded the SMCL of 300 μg/L), and pH (one of 22 samples above upper SMCL limit of 8.5).

Concentrations of some characteristics and constituents in water from wells completed in Quaternary terrace-deposit aquifers exceeded State of Wyoming standards for agricultural and livestock use in JH. The characteristic and constituent in environmental water samples from wells that had concentrations greater than agricultural-use standards were manganese (5 of 13 samples exceeded the WDEQ Class II standard of 200 μg/L) and SAR (1 of 20 samples exceeded the WDEQ Class II standard of 8). The value of one characteristic (pH) was outside the range for livestock-use standards (1 of 22 samples above upper WDEQ Class III limit of 8.5).

Overthrust Belt

The chemical composition of Quaternary terrace-deposit aquifers in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations are listed in **appendix E–5**. The TDS concentration from the spring (231 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L). No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards, indicating the water was suitable for most uses.

Star Valley

The chemical composition of Quaternary terrace-deposit aquifers in Star Valley (SV) was characterized and the quality evaluated on the basis of environmental water samples from as many as two wells. Individual constituent concentrations are listed in **appendix E–6**. The TDS concentration from one well sample (206 mg/L) indicated that the water was fresh (TDS concentrations less than or equal to 999 mg/L). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary terrace-deposit aquifers in the SV was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.1.3 Quaternary glacial-deposit aquifers

The chemical characteristics of groundwater from Quaternary glacial-deposit aquifers in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of glacial-deposit aquifers is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated as quantile values (**appendices E–1** to **E–5**).

Yellowstone Volcanic Area
The chemical composition of aquifers in Quaternary glacial-deposit aquifers in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituent concentrations for available constituents are listed in **appendix E–1**. The TDS concentration (91.0 mg/L) for the well sample indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–1**). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary glacial-deposit aquifers in the YVA was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Northern Ranges
The chemical composition of groundwater in Quaternary glacial-deposit aquifers in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs and six wells. Individual constituent concentrations for available constituents are listed in **appendix E–2**. Major-ion composition in relation to TDS for wells is shown on a trilinear diagram (**appendix F–2, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram B**). The TDS concentrations for the springs were 173 and 219 mg/L. TDS concentrations for the wells ranged from 162 to 228 mg/L, with a median of 178 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary glacial-deposit aquifers in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole
The chemical composition of Quaternary glacial-deposit aquifers in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as 4 springs and 37 wells. Summary statistics calculated for available constituents are listed in **appendix E–3**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–3, diagrams C and D**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagrams C and D**). The TDS concentrations for the springs ranged from 78.0 to 312 mg/L, with a median of 232 mg/L. TDS concentrations for the wells ranged from 18.0 to 378 mg/L, with a median of 176 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary glacial-deposit aquifers in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from wells completed in the Quaternary glacial-deposit aquifers in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent exceeded health-based standards: radon (one of two samples exceeded the proposed USEPA MCL of 300 pCi/L and the AMCL of 4,000 pCi/L). Concentrations of two constituents and one characteristic exceeded USEPA aesthetic standards for domestic use: manganese (2 of 7 samples exceeded the SMCL of 50 μg/L), iron (2 of 16 samples exceeded the SMCL of 300 μg/L), and pH (2 of 37 samples below lower SMCL limit of 6.5).

Concentrations of some characteristics and constituents in water from wells in Quaternary glacial-deposit aquifers exceeded State of Wyoming standards for agricultural and livestock use in JH. One constituent (manganese) was measured in environmental water samples from wells at concentrations greater than agricultural-use standards (1 of 7 samples exceeded the WDEQ Class II standard of 200 µg/L). One characteristic (pH) was measured at values outside the range for livestock-use standards (2 of 37 samples below lower WDEQ Class III limit of 6.5).

Green River and Hoback Basins
The chemical composition of Quaternary glacial-deposit aquifers in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of environmental water samples from three springs. Individual constituent concentrations are listed in **appendix E–4**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–4, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4; appendix F–4, diagram B**). TDS concentrations for the springs ranged from 205 to 228 mg/L, with a median of 224 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary glacial-deposit aquifers in the GH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt
The chemical composition of Quaternary glacial-deposit aquifers in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as three springs. Individual constituent concentrations are listed in **appendix E–5**. TDS concentrations from two springs (149 and 215 mg/L) indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary glacial-deposit aquifers in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.1.4 Quaternary landslide deposits

The chemical characteristics of groundwater from Quaternary landslide deposits in the Snake/Salt River Basin are described in this section of the report. Groundwater quality is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** to **E–5**).

Northern Ranges
The chemical composition of groundwater in Quaternary landslide deposits in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from three springs and one well. Individual constituent concentrations for available constituents are listed in **appendix E–2**, and major-ion composition in relation to TDS is shown on a trilinear diagram for the spring samples (**appendix F–2, diagram C**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram C**). TDS concentrations for the three springs ranged from 79.8 to 276 mg/L, with a median of 127 mg/L. The TDS concentration for the well sample was 495 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary landslide deposits in the NR was suitable for most uses. No characteristics or constituents in the spring samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some characteristics and constituents in water from Quaternary landslide deposits in the well sample in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. All environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. One characteristic (pH) exceeded the aesthetic standard for domestic use in the one well sample (pH above upper USEPA SMCL limit of 8.5).

Concentrations of some characteristics and constituents in water from the well completed in Quaternary landslide deposits exceeded State of Wyoming standards for agricultural and livestock use in the NR. One characteristic (SAR) was measured in the well sample at a concentration greater than the agricultural-use standard (WDEQ Class II standard of 8). One characteristic (pH) was measured at values greater than the upper livestock-use standard (above upper WDEQ Class III limit of 8.5).

Jackson Hole
The chemical composition of Quaternary landslide deposits in Jackson Hole (JH) was characterized and the quality evaluated on the basis of an environmental water sample from one spring. Individual constituent concentrations are listed in **appendix E–3**. The TDS concentration from the spring (179 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary landslide deposits in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Green River and Hoback Basins
The chemical composition of Quaternary landslide deposits in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of environmental water samples from three springs. Individual constituent concentrations are listed in **appendix E–4**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–4, diagram C**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4; appendix F–4, diagram C**). TDS concentrations for the springs ranged from 93.0 to 179 mg/L, with a median of 139 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from Quaternary landslide deposits in the GH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt
The chemical composition of Quaternary landslide deposits in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations are listed in **appendix E–5**. The TDS concentration from the spring (234 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L). On the basis of the characteristics and constituents analyzed for, the quality of water from the one spring issuing from Quaternary landslide deposits in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.1.5 Quaternary loess and lithified talus deposits

The chemical characteristics of groundwater from Quaternary loess and lithified talus deposits in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary loess and lithified talus deposits is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2),** and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole
The chemical composition of Quaternary loess and lithified talus deposits in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as four wells. Summary statistics calculated for

available constituents are listed in **appendix E–3**, and major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–3, diagram E**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagram E**). TDS concentrations for the wells ranged from 130 to 469 mg/L, with a median of 165 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from wells completed in Quaternary loess and lithified talus deposits in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.2 Leidy Formation

The Quaternary-age Leidy Formation (**pl. 5**) consists of very fine-grained, chocolate-brown, pink, and gray clay, laminated in part, interbedded with gray sand; lenticular quartzite pebble gravels; and basal quartzite boulder conglomerate in some places (Love and others, 1992). The Leidy Formation intertongues laterally with glacial drift and outwash deposits, and reported thickness ranges from 0 to 450 ft (Love and others, 1992). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit.

7.2.3 Quaternary and Tertiary volcanic rocks

Quaternary and Tertiary volcanic rocks are composed of intrusive igneous rocks, extrusive igneous rocks (primarily basalt and rhyolite), and beds of tuff and volcanic ash classified as many different lithostratigraphic units (**pls. 4, 5,** and **6**). Lithostratigraphic units composed either partially or entirely of tuff and volcanic ash in the Absaroka Volcanic Supergroup also could be classified as sedimentary rocks composed of volcaniclastic sediments, but they are grouped herein with the Quaternary and Tertiary volcanic rocks for convenience (for example, Wiggins Formation shown on **plate 6**). Quaternary and Tertiary volcanic rocks are essentially undeveloped in the Snake/Salt River Basin because they occur primarily in sparsely populated areas with no major population centers. Much of the areal extent of these rocks is within the boundary of Yellowstone National Park (**pls. 1** and **2**). Most investigations related to Quaternary and Tertiary volcanic rocks have been of thermal waters and related features in Yellowstone National Park (Gooch and Whitfield, 1888; Weed, 1889; Schlundt and Moore, 1909; Stearns and others, 1937; Fix, 1949; Morey and others, 1961; Marler, 1964; Rowe and others, 1965, 1973; Fournier and Rowe, 1966; Fournier and Truesdell, 1970; Fournier and Morgenstern, 1971; Marler and White, 1975; Thompson and others, 1975; Truesdell and Fournier, 1976a,b; Truesdell and others, 1977, 1978; Bargar, 1978; Pearson and Truesdell, 1978; Stauffer and Thompson, 1978, 1984; Thompson and Yadav, 1979; Stauffer and others, 1980; Thompson and Hutchinson, 1981; Friedman and Norton, 1982, 1990; Truesdell and Thompson, 1982; White and others, 1988; White, 1991; Rye and Truesdell, 1993, 2007; Fournier and others, 1994; Ball, Nordstrom, Cunningham, and others, 1998; Ball, Nordstrom, Jenne, and others, 1998; Ball and others, 2001, 2002; Gemery-Hill and others, 2007).

Information describing the physical and chemical characteristics of Quaternary and Tertiary volcanic rocks is sparse because few wells have been completed into the deposits. Hydrogeologic data describing Quaternary and Tertiary volcanic rocks in the Snake/Salt River Basin, including spring-discharge measurements and other hydraulic properties, are summarized on **plate 3**. Much of the information describing the characteristics of Quaternary and Tertiary volcanic rocks is from springs (commonly hot springs) issuing from the deposits (**pl .3; appendices E** and **F**).

Previous investigators have speculated that aquifer potential is poor (Wyoming Water Planning Program, 1972, Table III-2) or marginal (WWC Engineering and others, 2007, Figure 4-9). Other investigators have noted aquifer development potential is limited to localized areas with favorable hydrogeologic characteristics, and widespread development was unlikely because the rocks occur mostly within the boundaries of Yellowstone National Park and areas that are geographically inaccessible and located away from any substantial population (Cox, 1976, Sheet 1; Whitehead, 1996; Bartos and others, 2012). Cox (1976, Sheet 1) speculated on the potential well yield of the various Quaternary and Tertiary volcanic rocks and noted that the Yellowstone Group may yield a few tens of gallons per minute per well from porous and fracture zones" (rhyolitic ash, welded tuff, lava flows, breccia, and volcanic glass) or "may yield a few tens of gallons per minute per well from brecciated zones and fractures" (basalt lava flows). The investigator (Cox, 1976, Sheet 1) also speculated that the Absaroka Volcanic Supergroup, composed of andesitic, basaltic, and dacitic volcaniclastic rocks, "probably would not yield more than a few gallons per minute per well." Large springs issuing from Quaternary and Tertiary volcanic rocks in some areas indicate that permeability locally can be high, but is likely extremely variable because of widely varying rock types (Whitehead, 1996). In most areas, yields of wells completed in Quaternary and Tertiary volcanic rocks likely would only be adequate for domestic use (Whitehead, 1996).

Chemical characteristics

The chemical characteristics of saturated Quaternary and Tertiary volcanic rocks in the Snake/Salt River Basin (Quaternary basalt flows, Quaternary rhyolite flows, Yellowstone Group, and Tertiary volcanic rocks) are described in this section of the report.

7.2.3.1 Quaternary basalt flows

The chemical characteristics of groundwater from Quaternary basalt flows in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary basalt flows is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–1**).

Yellowstone Volcanic Area
The chemical composition of aquifers in Quaternary basalt flows in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituent concentrations for available constituents are listed in **appendix E–1**. The TDS concentration (69.0 mg/L) from the well indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–1**). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary basalt flows in the YVA was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.3.2 Quaternary rhyolite flows

The chemical characteristics of groundwater from Quaternary rhyolite flows in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary rhyolite flows is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–1**).

Yellowstone Volcanic Area
The chemical composition of Quaternary rhyolite flows in the YVA was characterized and the quality evaluated on the basis of environmental water samples from as many as 75 hot springs. Summary statistics calculated for available constituents are listed in **appendix E–1**. Major-ion composition in relation to TDS is shown on a trilinear diagram (**appendix F–1, diagram C**). TDS concentrations indicated that waters from one-half the hot springs were fresh (TDS concentrations less than or equal to 999 mg/L), and waters from the remaining one-half of the hot springs were slightly saline (1,000 to 2,999 mg/L) (**appendix E–1; appendix F–1, diagram C**). TDS concentrations for the hot

springs ranged from 298 to 1,470 mg/L, with a median of 1,000 mg/L.

Concentrations of some properties and constituents in water from rhyolite flows in the YVA hot springs approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of four constituents exceeded health-based standards: arsenic (the one sample analyzed for this constituent exceeded the USEPA MCL of 10 μg/L), mercury (the one sample analyzed for this constituent exceeded the MCL of 2 μg/L), fluoride (74 of 75 samples exceeded the USEPA MCL of 4 mg/L), and boron (1 of 75 samples exceeded the USEPA LHA of 6,000 μg/L). Concentrations of four constituents and two characteristics exceeded USEPA aesthetic standards for domestic use: aluminum (all 22 samples exceeded the lower SMCL standard of 50 μg/L and 12 of 22 samples exceeded the upper SMCL standard of 200 μg/L), fluoride (74 of 75 samples exceeded the SMCL of 2 mg/L), TDS (68 of 74 samples exceeded the SMCL of 500 mg/L), manganese (17 of 24 samples exceeded the SMCL of 50 μg/L), pH (9 of 73 samples below lower SMCL limit of 6.5 and 8 of 73 samples above upper SMCL limit of 8.5), and chloride (9 of 75 samples exceeded the SMCL of 250 mg/L).

Concentrations of some characteristics and constituents in water from hot springs in rhyolite flows exceeded State of Wyoming standards for agricultural and livestock use in the YVA. The characteristics and constituents in environmental water samples from hot springs that had concentrations greater than agricultural-use standards were mercury (one sample analyzed for this constituent exceeded the WDEQ Class II standard of 0.05 μg/L), SAR (71 of 74 samples exceeded the WDEQ Class II standard of 8), boron (71 of 75 samples exceeded the WDEQ Class II standard of 750 μg/L), chloride (45 of 75 samples exceeded the WDEQ Class II standard of 100 mg/L), lithium (7 of 73 samples exceeded the WDEQ Class II standard of 2,500 μg/L), manganese (2 of 24 samples exceeded the WDEQ Class II standard of 200 μg/L), and pH (2 of 73 samples above upper WDEQ Class II limit of 9). One characteristic and one constituent had values outside the range for livestock-use standards: pH (9 of 73 samples below lower WDEQ Class III limit of 6.5 and 8 of 73 samples above upper limit of 8.5) and boron (1 of 75 samples exceeded the WDEQ Class III standard of 5,000 μg/L).

The chemical composition of Quaternary rhyolite flows in the Yellowstone Volcanic Area (YVA) also was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs. Individual constituent concentrations are listed in **appendix E–1**. TDS concentrations (26.0 and 54.0 mg/L) indicated that both waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1**). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary rhyolite flows in the YVA was suitable for most uses. One characteristic (pH) was measured in both samples at values outside the range for USEPA aesthetic standards for domestic use and WDEQ livestock-use standards (below lower USEPA SMCL and WDEQ Class III limit of 6.5).

7.2.3.3 Yellowstone Group

The chemical characteristics of groundwater from the Yellowstone Group in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Yellowstone Group is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–1** and **F–1**).

Yellowstone Volcanic Area

The chemical composition of water from the Yellowstone Group in the YVA was characterized and the quality evaluated on the basis of environmental water samples from as many as 11 hot springs. Summary statistics calculated for available constituents are listed in **appendix E–1**. Major-ion composition in relation to TDS is shown on trilinear diagrams (**appendix F–1, diagram D**). TDS concentrations indicated that waters ranged from slightly saline (10 of 11 samples, concentrations between 1,000 to 2,999 mg/L) to fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1; appendix F–1, diagram D**). TDS concentrations in samples from the hot springs ranged from 734 to 1,430 mg/L, with a median of 1,210 mg/L.

Concentrations of some properties and constituents measured in water from hot springs issuing from the Yellowstone Group in the YVA approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Concentrations of five constituents measured in environmental waters exceeded health-based standards: antimony (all 4 samples exceeded the USEPA MCL of 6 μg/L), arsenic (all 4 samples exceeded the USEPA MCL of 10 μg/L), fluoride (all 11 samples exceeded the USEPA MCL of 4 mg/L), molybdenum (all 4 samples exceeded the USEPA LHA of 40 μg/L), and beryllium (2 of 4 samples exceeded the USEPA MCL of 4 μg/L). Concentrations of two characteristics and three constituents exceeded USEPA aesthetic standards for domestic use: TDS (all 11 samples exceeded the SMCL of 500 mg/L), fluoride (all 11 samples exceeded the SMCL of 2 mg/L), aluminum (3 of 4 samples exceeded the lower SMCL standard of 50 μg/L and 2 of 4 samples exceeded the upper SMCL standard of 200 μg/L), chloride (7 of 11 samples exceeded the SMCL of 250 mg/L), and pH (3 of 10 samples above upper SMCL limit of 8.5 and 1 of 10 samples below lower limit of 6.5).

Concentrations of some characteristics and constituents measured in water from hot springs issuing from the Yellowstone Group exceeded State of Wyoming standards for agricultural and livestock use in YVA. Characteristics and constituents measured in environmental water samples from hot springs at concentrations greater than agricultural-use standards were SAR (all 11 samples exceeded the WDEQ Class II standard of 8), arsenic (all 4 samples exceeded the WDEQ Class II standard of 100 μg/L), chloride (all 11 samples exceeded the WDEQ Class II standard of 100 mg/L), lithium (all 11 samples exceeded the WDEQ Class II standard of 2,500 μg/L), boron (10 of 11 samples exceeded the WDEQ Class II standard of 750 μg/L), mercury (2 of 4 samples exceeded the WDEQ Class II standard of 0.05 μg/L), and pH (2 of 10 samples above upper WDEQ Class II limit of 9). One constituent and one characteristic had values outside the range for livestock-use standards: arsenic (all 4 samples exceeded the WDEQ Class III standard of 200 μg/L) and pH (3 of 10 samples above upper WDEQ Class III limit of 8.5 and 1 of 10 samples below lower limit of 6.5).

The chemical composition of the Yellowstone Group in the Yellowstone Volcanic Area (YVA) also was characterized and the quality evaluated on the basis of environmental water samples from as many as six springs and six wells. Summary statistics calculated for available constituents are listed in **appendix E–1**, and major-ion composition in relation to TDS is shown on trilinear diagrams (**appendix F–1, diagrams E** and **F**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1; appendix F–1, diagrams E** and **F**). The TDS concentrations for the springs ranged from 22.0 to 133 mg/L, with a median of 55.0 mg/L. TDS concentrations for the wells ranged from 133 to 209 mg/L, with a median of 150 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Yellowstone Group in YVA was suitable for most uses. The concentration of one constituent (manganese) in one of two well samples analyzed for that constituent exceeded the USEPA aesthetic standards for domestic use (SMCL of 50 μg/L).

Northern Ranges

The chemical composition of the Yellowstone Group in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from two wells and one spring. Individual constituent concentrations are listed in **appendix E–2**. The TDS concentration measured in the spring sample was 61 mg/L and indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–2**). TDS was not measured in the two well samples. However, specific conductance was measured in both well samples, and both values (392 and 483 microsiemens per centimeter at 25 degrees Celsius, **appendix E–2**) would be much smaller than 999 mg/L when converted into equivalent TDS values by multiplying by 0.60 (Hem, 1985), indicating that both waters were fresh. On the basis of the characteristics and constituents analyzed for, the quality of water from the Yellowstone Group in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.3.4 Tertiary intrusive rocks

The chemical characteristics of groundwater from Tertiary intrusive rocks in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Tertiary intrusive rocks is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–3**).

Northern Ranges
The chemical composition of the Tertiary intrusive rocks in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from two wells. Individual constituent concentrations are listed in **appendix E–2**. The TDS concentrations (296 and 306 mg/L) indicated that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Tertiary intrusive rocks in NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable State of Wyoming domestic or livestock water-quality standards.

Jackson Hole
The chemical composition of the Tertiary intrusive rocks in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from two wells. Individual constituent concentrations are listed in **appendix E–3**. The TDS concentrations (275 and 288 mg/L) indicated that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for, the quality of water from Tertiary intrusive rocks in JH was suitable for most uses. Concentrations of one constituent exceeded health-based standards: radon (the 1 sample analyzed for this constituent exceeded the proposed USEPA MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L). Manganese was measured in one of the two well samples, and the concentration exceeded the USEPA aesthetic standard for domestic use (SMCL of 50 μg/L) and the State of Wyoming agricultural-use standard (WDEQ Class II standard of 200 μg/L).

7.2.3.5 Quaternary obsidian gravel and sand deposits

The physical and chemical characteristics of Quaternary obsidian gravel and sand deposits in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

One well completed in Quaternary unconsolidated deposits composed of gravel and sand with some silt and clay (Lowry and Gordon, 1964, p. 33) was inventoried as part of this study. The investigators reported that the unconsolidated deposits were overlain by rhyolite. Based on currently used lithostratigraphic terminology, the rhyolite overlying the unconsolidated deposits was interpreted herein to be the Lava Creek Tuff (Member B) of the Yellowstone Group (**pl. 6**). The gravel and sand-sized sediments were composed primarily of angular obsidian, so these deposits were informally named "Quaternary obsidian gravel and sand deposits" herein to reflect their unique composition and to differentiate them from other Quaternary unconsolidated deposits. Thickness of these deposits was at least 50 ft in the inventoried well. Existing hydrogeologic data for the well completed in these deposits, including well-yield and other hydraulic properties, are summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from Quaternary obsidian gravel and sand deposits in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Quaternary obsidian gravel and sand deposits is described in terms of the water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2)**.

Yellowstone Volcanic Area
The chemical composition of aquifers in Quaternary obsidian gravel and sand deposits in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituent concentrations for available constituents are listed in **appendix E–1**. The TDS concentration (183 mg/L) from the well indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–1**). On the basis of the characteristics and constituents analyzed for, the quality of water from Quaternary obsidian gravel and sand deposits in the YVA was suitable for most uses. One constituent (fluoride) exceeded the USEPA aesthetic standard for domestic use (SMCL of 2 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.4 Tertiary hydrogeologic units

The physical and chemical characteristics of Tertiary-age hydrogeologic units are described in this section of the report. Stock, domestic, and public-supply wells are completed in these units in the Snake/Salt River Basin. Tertiary hydrogeologic units are composed of lithostratigraphic units ranging from Pliocene to Paleocene in age (**pls. 4, 5,** and **6**). The Upper Cretaceous to Paleocene-age Pinyon Conglomerate (**pls. 5** and **6**) is described in this section for convenience. Tertiary hydrogeologic units are composed of nonmarine (continental) mixtures of shale, mudstone, siltstone, sandstone, conglomerate, lacustrine limestone, volcanic tuff, and other lithologies. Tertiary lithostratigraphic units commonly interfinger with other formations and lithologies. These units are relatively flat-lying and unconformably overlie eroded and older bedrock formations.

7.2.4.1 Heart Lake Conglomerate

The Pliocene Heart Lake Conglomerate (**pl. 6**) consists of abundant gray limestone and dolomite clasts, and sparse rhyolite and quartz clasts in a talc and clay matrix (Love and Christiansen, 1985). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.2 Shooting Iron Formation

The Pliocene Shooting Iron Formation (**pl. 5**) consists of pink, red, green, yellow, dark-gray, and brown bentonitic, mollusk-bearing, lacustrine and fluvial claystone; gray and yellow tuffaceous sandstone and siltstone; and pebble conglomerate of volcanic rock fragments in a bentonitic matrix (Love and others, 1992). Maximum thickness of the Shooting Iron Formation is greater than 100 ft (Love and others, 1992). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.3 Salt Lake aquifer

The physical and chemical characteristics of the Salt Lake aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

Saturated and permeable parts of the Pliocene and Miocene Salt Lake Formation compose the Salt Lake aquifer in the Snake/Salt River Basin (**pl. 4**). The Salt Lake Formation consists of pale reddish gray poorly to well-cemented conglomerate, sandstone, siltstone, clay/claystone, and beds of white volcanic ash (tuff) (Rubey, 1973a,b; Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey and others, 1980; Ahern and others, 1981, Table IV-1). Reported maximum thickness of the Salt Lake Formation in the Overthrust Belt is 1,000 ft (Lines and Glass, 1975, Sheet 1). The Salt Lake Formation is present in the structurally down-dropped valley floors within the Snake/Salt River Basin, most notably in the Star Valley area (Rubey, 1973a,b).

The Salt Lake Formation was classified as a major aquifer by Ahern and others (1981) and in the Statewide Framework Water Plan (WWC Engineering and others, 2007), and that definition was retained herein (**pl. 4**). Springs issuing from and wells completed in the aquifer provide water for domestic and public-supply use in the Snake/Salt River Basin (Forsgren Associates, 1991c, e, f, 1992, 1995; Trihydro Corporation, 1993a; Rendezvous Engineering, 2002; Rendezvous Engineering, PC, and Hinckley Consulting, 2009; Sunrise Engineering, 2009), primarily in Star Valley where the unit commonly underlies Quaternary unconsolidated deposits (**pl. 1**). Hydrogeologic data describing the Salt Lake aquifer in the Snake/Salt River Basin, including spring-discharge and well-yield measurements and other hydraulic properties, are summarized on **pl. 3**.

Salt Lake Formation permeability is both primary and secondary and highly localized. Lines and Glass (1975, Sheet 1) noted that conglomerates in the Salt Lake Formation were well cemented and poorly sorted, and consequently had little primary permeability; however, the investigators noted secondary permeability development may occur in areas where the formation is fractured, as exemplified by spring discharges as large as 8,000 gallons per minute (gal/min) from Flat Creek Springs, which is a spring issuing from fractured conglomerate in the Salt Lake Formation and is used to provide water to the town of Thayne in Star Valley. Subsequent studies of the Salt Lake Formation conducted in relation to public water-supply exploration and development in Star Valley have indicated that both primary and secondary permeability can be sufficient for public water-supply development, although aquifer productivity was highly spatially variable and dependent on local aquifer characteristics such as lithology and amount of fracturing (Forsgren Associates, 1992, 1993b,c, 1995, 1997, 2008; TriHydro Corporation, 1993a; Sunrise Engineering, 1995, 2009; Rendezvous Engineering, PC, 2002; Rendezvous Engineering, PC, and Hinckley Consulting, 2009). Where the Salt Lake Formation is composed primarily of fine-grained rocks (clay/claystone, siltstone, and tuff) and is unfractured, permeability is small and the formation is not an aquifer. In areas where impermeable, the Salt Lake Formation in Star Valley may "act as a leaky confining layer to underlying aquifers" (Forsgren Associates, 1995, p. 3-2).

Recharge to the Salt Lake aquifer in the Star Valley area is from direct infiltration of precipitation (snowmelt and rain), runoff, streamflow losses, and irrigation losses (Forsgren Associates, 1995; Rendezvous Engineering, PC, and Hinckley Consulting, 2009). This recharge occurs directly on aquifer outcrops, as well as through overlying Quaternary unconsolidated deposits.

Chemical characteristics

The chemical characteristics of groundwater from the Salt Lake aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Salt Lake aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2),** and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt

The chemical composition of the Salt Lake aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations are listed in **appendix E–5**. The TDS concentrations (193 and 202 mg/L) indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Salt Lake aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable

USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Star Valley
The chemical composition of the Salt Lake aquifer in Star Valley (SV) was characterized and the quality evaluated on the basis of environmental water samples from as many as 4 springs and 23 wells. Summary statistics calculated for available constituents are listed in **appendix E–6**, and major-ion composition in relation to TDS for wells completed in the aquifer is shown on a trilinear diagram (**appendix F–6, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–6; appendix F–6, diagram B**). TDS concentrations available for two of four springs were 236 and 287 mg/L. TDS concentrations for the wells ranged from 141 to 347 mg/L, with a median of 270 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from the Salt Lake aquifer in SV was suitable for all uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from wells in the Salt Lake aquifer in the SV approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of two constituents exceeded health-based standards: radon (the 1 sample analyzed for this constituent exceeded the proposed MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L) and radium-226 plus radium-228 [1 of 3 samples exceeded the USEPA MCL of 5 pCi/L]. Concentrations of two constituents exceeded USEPA aesthetic standards for domestic use: iron (1 of 11 samples exceeded the SMCL of 300 μg/L) and manganese (1 of 11 samples exceeded the SMCL of 50 μg/L).

Concentrations of some characteristics and constituents in water from wells in the Salt Lake aquifer exceeded State of Wyoming standards for agricultural and livestock use in SV. Two constituents in environmental water samples from wells were measured at concentrations greater than agricultural-use standards: radium-226 plus radium-228 (1 of 3 samples exceeded the WDEQ Class II standard of 5 pCi/L) and iron (1 of 11 samples exceeded the WDEQ Class II standard of 5,000 μg/L). The concentration of one constituent (radium-226 plus radium-228) exceeded the livestock-use standard (1 of 3 samples exceeded the WDEQ Class III standard of 5 pCi/L).

7.2.4.4 Miocene gravel deposits

The physical and chemical characteristics of Miocene gravel deposits in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

Unnamed gravel deposits of Miocene age ("Miocene gravel deposits") are composed of gray, unconsolidated gravel to poorly cemented conglomerate that underlies the Conant Creek Tuff on the northeast and east sides of Signal Mountain; clasts are composed primarily of rounded quartzite, Paleozoic and Mesozoic sedimentary rock fragments, and Tertiary andesite (Love, 1989; Love and others, 1992). The unnamed gravel deposits are estimated to be 1,000- to 1,200-ft thick and have been identified only on Signal Mountain (Love, 1989, p. C40; Love and others, 1992).

Chemical characteristics

The chemical characteristics of groundwater from Miocene gravel deposits in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of Miocene gravel deposits is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole
The chemical composition of groundwater from

Miocene gravel deposits in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituent concentrations for available constituents are listed in **appendix E–3**. The TDS concentration (102 mg/L) from the well sample indicated that the water was fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for, the quality of water from Miocene gravel deposits in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.4.5 Camp Davis aquifer

The physical and chemical characteristics of the Camp Davis aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

Saturated and permeable parts of the Miocene Camp Davis Formation compose the Camp Davis aquifer in the Snake/Salt River Basin (**pls. 4, 5**) (Love and Christiansen, 1985). The Camp Davis Formation consists of conglomeratic lower and upper members separated by a middle member composed of lacustrine limestone, siltstone, and tuff (Love, 1956a,c; Olson and Schmitt, 1987, and references therein). Reported thickness of the Camp Davis Formation in the Overthrust Belt ranges from about 100 to 5,500 ft (Love, 1956a, b, c; Schroeder, 1973, 1974, 1976, 1987; Love and Love, 2000).

Hydrogeologic data describing the Camp Davis aquifer in the Snake/Salt River Basin, including spring-discharge and well-yield measurements are summarized on **plate 3**. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Camp Davis Formation might be a fair to good aquifer (**pls. 4** and **5**). The Camp Davis Formation was classified as a major aquifer by Ahern and others (1981) and as a marginal aquifer in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4** and **5**). Cox (1976, Sheet 1) speculated that conglomerate in the Camp Davis Formation might "yield a few tens of gallons per minute from conglomerate," larger than the two well yields (2 and 10 gal/min) inventoried for the formation as part of this study (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Camp Davis aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Camp Davis aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–3** and **E–5**).

Jackson Hole
The chemical composition of the Camp Davis aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as three springs and one well. Individual constituents are listed in **appendix E–3**. Major-ion composition in relation to TDS for springs issuing from the Camp Davis aquifer is shown on a trilinear diagram (**appendix F–3, diagram F**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagram F**). TDS concentrations for the springs ranged from 252 to 292 mg/L, with a median of 288 mg/L. The TDS concentration for the well was 180 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from three springs issuing from the Camp Davis aquifer in JH was suitable for most uses. One constituent (aluminum) exceeded USEPA aesthetic standards for domestic use (1 of 2 samples above lower SMCL standard of 50 μg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and

constituents in water from one well completed in the Camp Davis aquifer in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. One constituent (fluoride) was measured at a concentration greater than a health-based standard (USEPA MCL of 4 mg/L) and one constituent (arsenic) was measured at a concentration equal to its health-based standard (USEPA MCL of 10 μg/L). Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: pH (exceeded the upper SMCL limit of 8.5) and fluoride (exceeded the SMCL of 2 mg/L). No characteristics or constituents in the well sample approached or exceeded applicable State of Wyoming standards for agricultural-use standards. One characteristic (pH) was measured at values that exceeded the livestock-use standard (upper WDEQ Class III standard of 8.5).

Overthrust Belt

The chemical composition of the Camp Davis aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituent concentrations are listed in **appendix E–5**. The TDS concentration (306 mg/L) from the well indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Camp Davis aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.4.6 Teewinot aquifer

The physical and chemical characteristics of the Teewinot aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

Saturated and permeable parts of the Miocene Teewinot Formation compose the Teewinot aquifer in the Snake/Salt River Basin (**pls. 4** and **5**). The Teewinot Formation consists of chalky white to light-gray, soft, porous limestone, claystone, and pumicite (Love, 1956a; Love and others, 1992). The upper part of the formation is very fossiliferous, thin-bedded claystone, marlstone, and tuff, and the lower two-thirds of the formation is composed primarily of nodular porous limestone in 100- to 200-ft thick beds interbedded with pumicite in 20- to 75-ft thick beds (Love, 1956a; Love and others, 1992). A 110-ft thick conglomerate composed of limestone, quartzite, and obsidian clasts is present in the middle part of the formation (Love, 1956a, b; Love and others, 1992). Reported thickness of the Teewinot Formation is as much as 6,000 ft or more (Love and others, 1992; Love and Reed, 2000, 2001a,b; Love, 2001a,b,c, 2003b).

The Wyoming Water Planning Program (1972, Table III-2) speculated that the Teewinot Formation might be a poor aquifer (**pls. 4** and **5**). The Teewinot Formation was classified as a major aquifer by Ahern and others (1981) and in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4** and **5**). Hydrogeologic data describing the Teewinot aquifer in the Snake/Salt River Basin, including spring-discharge and well-yield measurements, are summarized on **plate 3**. Cox (1976, Sheet 1) reported yields as much as 120 gal/min per well from fractures and solution channels in limestone in the formation. Yields of four wells completed in the Teewinot aquifer inventoried as part of this study were smaller than reported by Cox, ranging from 10 to 50 gal/min (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Teewinot aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Teewinot aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole
The chemical composition of the Teewinot aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as three springs and three wells. Individual constituents are listed in **appendix E–3**. Major-ion composition in relation to TDS for springs issuing from and wells completed in the Teewinot aquifer is shown on trilinear diagrams (**appendix F–3, diagrams G** and **H**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; appendix F–3, diagrams G** and **H**). The TDS concentrations for the springs ranged from 244 to 254 mg/L, with a median of 247 mg/L. The TDS concentration for the wells ranged from 166 to 260 mg/L, with a median of 212 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Teewinot aquifer in springs and wells in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.4.7 Colter Formation

The physical and chemical characteristics of the Colter Formation in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Miocene Colter Formation in the Snake/Salt River Basin (**pls. 5** and **6)** consists of pyroclastic conglomerate, sandstone, and claystone (Love, 1956a; Love and others, 1992). Reported thickness of the Colter Formation in the Jackson Hole area is as much as 7,000 ft (Love, 1956a; Love and others, 1992).

The Wyoming Water Planning Program (1972, Table III-2) speculated that the Colter Formation might be a fair to poor aquifer (**pls. 5** and **6**). Cox (1976, Sheet 1) speculated that the Colter Formation might yield a few gallons per minute per well. Few hydrogeologic data describing the Colter Formation in the Snake/Salt River Basin were inventoried as part of this study, but one available spring-discharge measurement (1 gal/min) is shown on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Colter Formation in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Colter Formation is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole
The chemical composition of the Colter Formation in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–3**. The TDS concentration (114 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Colter Formation in one spring in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.2.4.8 White River aquifer

Saturated and permeable parts of the Oligocene White River Formation compose the White River aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The White River Formation consists of white nodular calcareous siltstone and pale-green bentonitic claystone that locally can contain vertebrate fossils (Love and others, 1992). Reported thickness of the White River Formation in the Overthrust Belt ranges from 0 to 200 ft (Lines and Glass, 1975, Sheet 1; Love and others, 1992; Love, 2002). Despite the predominant fine grain size of sediments composing the unit, the formation is tentatively classified as an aquifer herein (**pls. 5** and **6**). The White River Formation generally is defined as an aquifer throughout Wyoming where permeable, including areas immediately east of the Snake/Salt River Basin in the Wind River and Bighorn Basins (**pls. 5** and **6**). Permeability in the predominantly fine-grained rocks composing the unit is provided primarily by local secondary permeability development (for example, fractures), and much less commonly occurring local coarse-grained zones (Bartos and others, 2012). In areas where secondary permeability or coarse-grained zones are not present, the formation is defined as a confining unit. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.9 Conglomerate of Sublette Range

The Eocene and Paleocene Conglomerate of Sublette Range of Love and others (1993) (**pl. 4**) [also called the Sublette Range Conglomerate (Salat and Steidtmann, 1991)] consists of white, pink, dark gray, well-rounded, poorly sorted, pebble to boulder gravel composed of quartzite and gray chert mixed with silt and sand (Love and Christiansen, 1985, Sheet 2; Salat, 1989; Salat and Steidtmann, 1991). Reported maximum thickness of the Conglomerate of Sublette Range is about 591 ft (Oriel and Platt, 1980). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.10 Wasatch aquifer (Overthrust Belt)

The Eocene Wasatch Formation comprises the Wasatch aquifer within the Overthrust Belt part of the Snake/Salt River Basin (**pl. 4**). The Wasatch aquifer is undeveloped as a water supply within the Snake/Salt River Basin study boundary within the Overthrust Belt. However, immediately south in the Bear River Basin within the Overthrust Belt, the aquifer is used as a source of water for domestic, stock, industrial, and public-supply purposes (Bartos and others, 2014). Characteristics of the Wasatch aquifer in the Snake/Salt River Basin likely are similar to those in the Bear River Basin.

The Wasatch Formation consists of variegated mudstone, claystone, siltstone, shale, sandstone, conglomeratic sandstone, and conglomerate. It is a thick sequence of nonmarine sedimentary rock with named members of the formation (described below but individual members not shown on **plate 4**) in some areas of the Overthrust Belt.

The Wasatch Formation in the Overthrust Belt (including the Snake/Salt River Basin) is divided into a basal conglomerate, a lower unnamed member, the main body of the formation, and the Bullpen and Tunp Members (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993) (individual members not shown on Plate 4). The basal conglomerate is a lenticular conglomerate of sandstone pebbles and cobbles, and ranges from 0 to 300 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; M'Gonigle and Dover, 1992). The lower unnamed member is composed predominantly of drab-colored mudstone and sandstone, and ranges from 0 to 300 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; M'Gonigle and Dover, 1992). The main body is composed predominantly of red, purple, and tan mudstone, with some sandstone, and ranges from 1,500 to 2,000 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The Bullpen Member is composed predominantly of red and salmon mudstone, and gray and brown mudstone, and ranges from 0 to 400 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; M'Gonigle and Dover, 1992). The Tunp Member is composed of conglomeratic mudstone and diamictite, and ranges from 200 to 500 ft in thickness (Oriel and Tracey, 1970; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; Hurst, 1984; Hurst and Steidtmann, 1986; M'Gonigle and Dover, 1992).

The Wasatch Formation is considered to be an aquifer in the Overthrust Belt by previous investigators (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern and others, 1981; Forsgren Associates, 2000; TriHydro Corporation, 2000, 2003) (**pl. 4**). In the Wyoming Water Framework Plan, the Wasatch Formation is classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**). The Wasatch aquifer is an important aquifer in the adjacent Green River Basin to the east (Ahern and others, 1981; Martin, 1996; Naftz, 1996; Glover and others, 1998; Bartos and Hallberg, 2010). Ahern and others (1981, Figure II-7) classified the formation as a major aquifer in the Overthrust Belt (**pl. 4**) and noted that both springs issuing from and wells completed in the formation locally yielded water. The Wasatch Formation has been defined as a "productive aquifer" in the Deer Mountain Subdivision area near the town of Bear River in the Bear River Basin located immediately south of the Snake/Salt River Basin (Forsgren Associates, 2000; TriHydro Corporation, 2000).

Although little information was available at the time of their studies, previous investigators speculated that small to moderate yields sufficient for domestic and stock use were likely from permeable beds in the Wasatch Formation in the Overthrust Belt (Berry, 1955; Robinove and Berry, 1963; Wyoming Water Planning Program, 1972, Table III-2). Lines and Glass (1975, Sheet 1) noted that conglomeratic sandstones and conglomerates in the Wasatch Formation likely were capable of yielding "moderate to large quantities" of water to wells. In addition, the investigators (Lines and Glass, 1975, Sheet 1) noted that fine-grained sandstones in the Wasatch Formation were capable of yielding "small to moderate" quantities of water, but that well yields were likely "greatly dependent" on the saturated thickness of the sandstone beds. Similarly, Ahern and others (1981) noted that permeable sandstones, conglomeratic sandstones, and conglomerates of the Wasatch Formation could yield moderate to large quantities of water to wells. Sandstones, conglomeratic sandstones, and conglomerates composing the Wasatch aquifer primarily are under confined conditions, except in outcrop areas where unconfined (water-table) conditions are present. Although no data were located describing the physical and chemical characteristics of the hydrogeologic unit within the boundary of the Snake/Salt River Basin, Wasatch aquifer characteristics in the Bear River Basin to the south and within the Overthrust Belt are provided in Bartos and others (2014).

7.2.4.11 Wasatch-Fort Union aquifer (Green River and Hoback Basins)

The physical and chemical characteristics of the Wasatch-Fort Union aquifer in the Green River and Hoback Basins within the Snake/Salt River Basin are described in this section of the report. The Wasatch-Fort Union aquifer is composed of two zones represented by the Wasatch and Fort Union Formations and related formations such as the Pass Peak and Hoback Formations (Bartos and Hallberg, 2010, Figure 5-1, and references therein). The aquifer forms the base of the lower Tertiary aquifer system in the Green River Basin, and is in direct contact with underlying Upper Cretaceous rocks at the top of the Mesaverde aquifer (Bartos and Hallberg, 2010, Figure 5-1). No regional confining unit separates the lower Tertiary aquifer system in the Green River Basin from the underlying Mesaverde aquifer. The Wasatch-Fort Union aquifer is the thickest Cenozoic hydrogeologic unit in the Green River Basin, as much as 11,000-ft thick.

Physical characteristics

The physical characteristics of the Wasatch and Fort Union zones of the Wasatch-Fort Union aquifer in the Green River and Hoback Basins within the Snake/Salt River Basin are described in this section of the report.

7.2.4.12 Wasatch Zone of the Wasatch-Fort Union aquifer (including Pass Peak Formation)

The Wasatch zone of the Wasatch-Fort Union aquifer is composed of the Wasatch Formation (main body), undifferentiated Green River and Wasatch Formations along the western edge of the Green River Basin, the Pass Peak Formation in the northwestern Green River Basin, various Eocene (and possibly younger) rocks in the northeastern Green River Basin, as well as numerous small tongues and members including the Farson Sandstone Member of the Green River Formation and the Alkali Creek Member of the Wasatch Formation between the New Fork River and the southernmost exposure of the Laney aquifer in the north and central Green River Basin; the Niland Tongue of the Wasatch Formation in the southeast Green River Basin; the "La Barge Member"; the Chappo Member of the Wasatch Formation; and the Luman Tongue of the Green River Formation in the southeast Green River Basin (Martin, 1996; Glover and others, 1998; Bartos and Hallberg, 2010, and references therein). The Eocene Pass Peak Formation consists of conglomerate, sandstone, and shale; thickness is as much as 5,000 ft (Welder, 1968, Sheet 2; Cox, 1976, Sheet 1).

Sandstone beds, interbedded with various fine-grained sedimentary rocks in these various units composing the Wasatch zone, generally provide most of the water to wells completed in the aquifer. The thickness and amount of sandstone at a given location generally depends on the distance from the sediment source area. Throughout the northern Green River Basin, many investigators have noted thick, permeable, areally extensive sandstones at or near land surface. In fact, Welder (1968, sheet 2) noted that "aggregate thickness of water-bearing sandstone probably ranges from one-third to two-thirds of total formation thickness; consequently, a large amount of water is in storage and the water is under pressure where deeply buried." In the southern Green River Basin, the Wasatch zone is overlain by the Green River Formation, and the number and thickness of sandstone beds in the aquifer varies greatly both laterally and vertically. Large well yields in thick sandstone have been reported along basin margins. Welder (1968, Sheet 2) speculated that groundwater-development possibilities were "good" in the Green River Basin. Cox (1976, Sheet 1) speculated that conglomerate and sandstone in the Pass Peak Formation might "yield a few tens of gallons per minute per well," larger than the two well yields (2 and 5 gal/min) inventoried for the formation as part of this study (**pl. 3**).

Groundwater in the Wasatch zone of the Wasatch-Fort Union aquifer in the Green River Basin generally flows from basin margins (assumed to represent recharge areas) toward the center of the basin and to the south (assumed to represent discharge areas) (Martin, 1996). Water-table conditions in the aquifer predominate in the northern Green River Basin, whereas artesian (confined) conditions predominate elsewhere.

7.2.4.13 Fort Union Zone of the Wasatch-Fort Union aquifer (including the Hoback Formation)

The Fort Union zone of the Wasatch-Fort Union aquifer is composed of the Fort Union Formation and the Hoback Formation (Martin, 1996; Glover and others, 1998; Bartos and Hallberg, 2010, and references therein). The Hoback Formation is equivalent to the Fort Union Formation in the northwestern Green River Basin. The Fort Union Formation is lithologically very similar to the Wasatch Formation; it is also composed of fluvial sandstones and fine-grained sedimentary rocks. In the subsurface, it is often difficult to differentiate the two formations. The Hoback Formation is composed of gray and brown sandstone, conglomerate, shale, siltstone, and shaley limestone; maximum thickness is about 16,000 ft, but the formation thins southward in its outcrop area to about 8,000 ft (Spearing, 1969, Figure 4; Lines and Glass, 1975, Sheet 1; Cox, 1976, Sheet 1). Although the Fort Union zone is present throughout the Green River Basin, Martin (1996, p. 21) noted that the "northwestern part of the [Green River] structural basin where the Hoback Formation is exposed at the surface, the Fort Union zone is not included as part of the aquifer system because it is north of a groundwater divide outside of the hydrologic basin."

Few hydrologic data are available for the Hoback Formation in the Snake/Salt River Basin (**pl. 3**), but because of large thicknesses of sandstone and conglomerate, it is considered a potential source of water (Lines and Glass, 1975, Sheet 1). Cox (1976, Sheet 1) speculated that sandstone in the Hoback Formation might "yield a few tens of gallons per minute per well," similar to the one well yield (20 gal/min) inventoried for the formation as part of this study (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Wasatch-Fort Union aquifer (samples collected from the Pass Peak and Hoback Formations) in the Snake/Salt River Basin, are described in this section of the report. Groundwater quality from both the Pass Peak and Hoback Formations is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–4**).

Green River and Hoback Basins
The chemical composition of the Wasatch-Fort Union aquifer (samples collected from the Pass Peak Formation) in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations are listed in **appendix E–4**. TDS concentrations (283 and 367 mg/L) indicated that waters from both springs were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Wasatch-Fort Union aquifer (Pass Peak Formation) in the GH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of the Wasatch-Fort Union aquifer (samples collected from the Hoback Formation) in the GH was characterized and the quality evaluated on the basis of environmental water samples from one spring and two wells. Individual constituent concentrations are listed in **appendix E–4**. TDS concentrations for the spring (275 mg/L) and for the wells (215 and 327 mg/L) indicated waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4**). One constituent (mercury) measured in the spring sample was greater than the State of Wyoming agricultural-use standard (WDEQ Class II standard of 0.05 μg/L). No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic or livestock water-quality standards in the spring sample. On the basis of the characteristics and constituents analyzed for, the quality of water from the two wells completed in the Wasatch-Fort Union aquifer (Hoback Formation) in the GH was suitable for most uses. No characteristics or constituents measured in the two well samples approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards in environmental samples from wells.

7.2.4.14 Tepee Trail Formation

The Eocene Tepee Trail Formation in the Snake/Salt River Basin (**pls. 5** and **6)** consists of tuffaceous sandstone, mudstone, and claystone (Love, 1956a; Love and others, 1992). Reported thickness of the Tepee Trail Formation in the Jackson Hole area is as much as 1,500 ft (Love and Keefer, 1972). For the Wind River Basin, Bartos and others (2012, Plate 2) assigned the Tepee Trail Formation to part of a confining unit identified as the "Aycross-Wagon Bed confining unit" (**pls. 5** and **6**) composed of the volcaniclastic Eocene Tepee Trail and Aycross Formations or siliciclastic Wagon Bed Formation. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.15 Hominy Peak Formation

The Eocene Hominy Peak Formation in the Snake/Salt River Basin (**pls. 5** and **6)** consists of mafic volcaniclastic conglomerate, tuff with sparse claystone in the upper part of the formation, and gold-bearing conglomerate at the base of the formation (Love and others, 1978). The formation is exposed at the north end and on the west flank of the Teton Range and the south boundary of Yellowstone National Park (**pl. 1**). Love and others (1978) assigned the formation to the Absaroka Volcanic Supergroup of Smedes and Prostka (1972). Reported thickness of the Hominy

Peak Formation is as much as 2,000 ft (Love and others, 1978). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.16 Aycross Formation

The Eocene Aycross Formation in the Snake/Salt River Basin (**pls. 5** and **6**) consists of tuffaceous sandstone, mudstone, and claystone (Love, 1956a; Love and others, 1992). Reported thickness of the Aycross Formation in the Jackson Hole area is as much as 1,500 ft (Love, 1956a; Rohrer and Obradovich, 1969). In the Wind River Basin, Bartos and others (2012, Plate 2) assigned the Aycross Formation to part of a confining unit identified as the "Aycross-Wagon Bed confining unit" (**pls. 5** and **6**) composed of the volcaniclastic Eocene Tepee Trail and Aycross Formations or siliciclastic Wagon Bed Formation. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.17 Crandall Conglomerate

The Eocene Crandall Conglomerate (**pl. 6**) is a clast-supported conglomerate composed of locally derived Paleozoic carbonate clasts (Love and Christiansen, 1985; Breeden and others, 2012). Thickness of the formation is as much as 328 ft (Breeden and others, 2012). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.2.4.18 Wind River aquifer

Present within a small part of the east-central Snake/Salt River Basin study area (**pls. 1** and **2**), the Wind River aquifer consists of the Eocene Wind River Formation (**pls. 5** and **6**) (Bartos and others, 2012, and references therein). Thickness of the Wind River Formation in the Wind River Basin ranges from about 100 ft along mountain flanks to about 5,000 ft in the central part of the Wind River Basin (Bartos and others, 2012, and references therein). The Wind River Formation is composed of an interbedded sequence of claystone, shale, siltstone, and conglomerate, with lenticular beds of fine- to coarse-grained sandstone of variable thickness and areal extent; small amounts of bentonite, tuff, and limestone also may be present (Morris and others, 1959; McGreevy and others, 1969; Richter, 1981). Coarser deposits may be more abundant along the basin margins because of proximity to sediment sources such as the Washakie Range and Wind River Mountains (Whitcomb and Lowry, 1968).

In the Wind River Basin, the Wind River aquifer is underlain by the Indian Meadows confining unit or by the Fort Union aquifer, in the absence of the Eocene Indian Meadows Formation (Bartos and others, 2012, Plate II). In the Wind River Mountains, the Wind River Formation may be underlain by the Conglomerate of Roaring Fork (Bartos and others, 2012, Plate II). Where buried in the Wind River Basin, the aquifer is overlain by the Aycross-Wagon Bed confining unit [composed of the volcaniclastic Eocene Tepee Trail and Aycross Formations or siliciclastic Wagon Bed Formation (Bartos and others, 2012, Plate II)], or Quaternary unconsolidated deposits (Bartos and others, 2012, Plate II).

The Wind River aquifer is used as a source of water for domestic, stock, irrigation, industrial, and public-supply purposes throughout the Wind River Basin (Richter, 1981; Bartos and others, 2012). Many wells are installed in the Wind River aquifer in the Wind River Basin because it is present at or near land surface (crops out) throughout most of the basin. Most wells completed in the Wind River aquifer are for stock and domestic use because of relatively low yields and water quality that may preclude some uses without treatment (Morris and others, 1959; Whitcomb and Lowry, 1968; McGreevy and others, 1969; Richter, 1981; Bartos and others, 2012). Because of limited areal extent and location away from any population, the aquifer is unused in the Snake/Salt River Basin. No data were located describing the physical and chemical characteristics of the hydrogeologic unit in the Snake/Salt River Basin.

7.2.4.19 Devils Basin Formation

The Paleocene Devils Basin Formation (**pl. 5**) consists of gray, soft, lenticular, poorly bedded sandstones; bedded gray and pale-green siltstones and claystones; thin-bedded brown to black carbonaceous shale; and thin beds of coal (Love, 1989). Thickness of the type section is about 1,500 ft (Love, 1989). No data were located describing the physical and chemical hydrogeologic characteristics of the Devils Basin Formation in the Snake/Salt River Basin.

7.2.4.20 Pinyon Conglomerate

The Upper Cretaceous to Paleocene Pinyon Conglomerate (**pls. 5** and **6**) consists of rusty-brown conglomerate composed of quartzite cobbles and pebbles in a matrix of rusty coarse-grained sandstone and occasional boulders of older conglomerate and quartzite (Lindsey, 1972; Love and others, 1992). The formation is as much as 3,800-ft thick in the Snake/Salt River Basin (Lindsey, 1972; Love, 1974a,b, 2001c, 2003b; Love and others, 1992). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Pinyon Conglomerate might be a "fair to poor aquifer." Cox (1976, Sheet 1) speculated that wells completed in the formation might yield a few tens of gallons per minute per well. No data were located describing the physical and chemical hydrogeologic characteristics of the Pinyon Conglomerate in the Snake/Salt River Basin.

7.3 Mesozoic hydrogeologic units

Mesozoic hydrogeologic units (aquifers and confining units) are described in this section of the report. Lithostratigraphic units of Cretaceous, Jurassic, and Triassic age compose the Mesozoic hydrogeologic units (aquifers and confining units) in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Depending on location and depth, wells completed in Mesozoic hydrogeologic units produce highly variable quantities and quality of water. The highly complex structural features of the Overthrust Belt require site-specific geologic and hydrogeologic investigation to characterize and develop groundwater resources from Mesozoic hydrogeologic units.

Development of most Mesozoic aquifers in the Snake/Salt River Basin has been very limited to date (2014), except in areas where aquifers crop out and are directly exposed at land surface or at shallow depth below younger hydrogeologic units. Hydraulic properties, great depth, minimal precipitation and recharge, and generally poor water quality except near recharge areas prevents extensive groundwater development of aquifers in Mesozoic hydrogeologic units.

7.3.1 Landslide Creek Formation

The Upper Cretaceous Landslide Creek Formation (**pl. 6**) consists of greenish-gray, bentonitic, tuffaceous sandstone and conglomerate (Love and Christiansen, 1985). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Landslide Creek Formation might be a poor aquifer (**pl. 6**). No data were located describing the physical and chemical hydrogeologic characteristics of the Landslide Creek Formation in the Snake/Salt River Basin.

7.3.2 Harebell Formation

The physical and chemical characteristics of the Harebell Formation in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Upper Cretaceous Harebell Formation (**pls. 5** and **6**) consists of sandstone, shale, conglomerate, sandstone, claystone, and tuff (Love, 1956a; Lindsey, 1972; Love and others, 1992). The conglomerate consists of quartzite roundstones in a matrix of brown, gold-bearing sandstone. The sandstone is brown, gray, dull green, silty, hard, and tuffaceous. The claystone is gray, dark green, black, and mustard yellow, silty, and tuffaceous. Reported maximum thickness of the Harebell Formation ranges from 5,000 to 10,000 ft (Love, 1974a,b, 1975a,b, 2002; Love and others, 1992).

Few hydrogeologic data are available describing the hydrogeologic characteristics of the Harebell

Formation in the Snake/Salt River Basin. Hydrogeologic data describing the physical characteristics of the Harebell Formation, including well-yield measurements and other hydraulic properties, are summarized on **plate 3**. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Harebell Formation might be a good aquifer (**pls. 5** and **6**). The Harebell Formation was classified as a marginal aquifer in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Cox (1976, Sheet 1) speculated that the Harebell Formation might yield a few tens of gallons per minute per well from conglomerate and sandstone. Yields of two wells completed in the Harebell Formation inventoried as part of this study (12 and 20 gal/min) were similar to those speculated by Cox (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Harebell Formation in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Harebell Formation is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2),** and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole

The chemical composition of the Harebell Formation in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from one spring and two wells. Individual constituents are listed in **appendix E–3**. TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**). The TDS concentration for the spring was 278 mg/L. The TDS concentrations for the wells were 280 and 314 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from the Harebell Formation in the spring in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from wells completed in the Harebell Formation approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, but concentrations of one constituent (fluoride) exceeded health-based standards (1 of 2 samples exceeded the USEPA MCL of 4 mg/L). Concentrations of one characteristic and one constituent exceeded aesthetic standards for domestic use: pH (1 of 2 samples exceeded the upper SMCL limit of 8.5) and fluoride (1 of 2 samples exceeded the SMCL of 2 mg/L).

Concentrations of some characteristics and constituents in water from wells completed in the Harebell Formation exceeded State of Wyoming standards for agricultural and livestock use in JH. Two characteristics in the wells approached or exceeded applicable State of Wyoming standards for agricultural-use standards: pH (1 of 2 samples exceeded upper WDEQ Class II standard of 9) and SAR (1 of 2 samples exceeded WDEQ Class II standard of 8). The value of one characteristic (pH) exceeded the livestock-use standard (1 of 2 samples exceeded upper WDEQ Class III standard of 8.5).

7.3.3 Meeteetse Formation

The Upper Cretaceous Meeteetse Formation (**pl. 5**) consists of chalky-white to gray salt-and-pepper soft sandstone, interbedded with yellow, pale green, and dark-gray carbonaceous shale, thin coal beds, white slabby tuff, and yellow to gray bentonite beds (Love and others, 1992). Conglomerate in the formation consists of quartzite cobbles that can be in a gold-bearing sandstone matrix in some horizons. Maximum thickness of the formation ranges from about 500 to 1,000 ft (Cox, 1976, Sheet 1; Love, 1975a, 2002, 2003b; Love and others, 1992).

Few hydrogeologic data are available describing the hydrogeologic characteristics of the Meeteetse Formation in the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Meeteetse Formation might be a poor aquifer in the Snake/Salt River Basin (**pl. 5**). The Meeteetse Formation was classified as a major aquitard in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pl. 5**). Cox (1976, Sheet 1) speculated that the Meeteetse Formation might yield a few tens of gallons per minute per well from sandstone. No data were located describing the physical and chemical hydrogeologic characteristics of the hydrogeologic unit in the Snake/Salt River Basin.

7.3.4 Mesaverde aquifer

Saturated and permeable parts of the Upper Cretaceous Mesaverde Formation compose the Mesaverde aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The Mesaverde Formation (**pls. 5** and **6)** consists of white massive to thick-bedded, soft, porous, medium- to coarse-grained sandstone interbedded with thin gray shale and sparse coal and bentonite beds (Love and others, 1992). Conglomerate beds containing quartzite cobbles in a gold-bearing matrix occur locally in the Grand Teton National Park area. Maximum thickness of the formation ranges from about 800 to 1,200 ft or more (Rohrer, 1969; Cox, 1976, Sheet 1; Love, 1975a, 2002, 2003b; Love and others, 1992).

Few hydrogeologic data are available describing the hydrogeologic characteristics of the Mesaverde Formation in the Snake/Salt River Basin, so much of what is known about the hydrogeologic characteristics of the formation is from adjacent structural basins. The Mesaverde Formation generally is defined as an aquifer throughout Wyoming, including the Overthrust Belt and in areas immediately east of the Snake/Salt River Basin in the Wind River and Bighorn Basins, and southeast in the Green River Basin (**pls. 5** and **6**); consequently, the Mesaverde Formation in the Snake/Salt River Basin was classified as an aquifer herein (**pls. 5** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Mesaverde Formation might be a poor aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). Ahern and others (1981) classified the Mesaverde Formation as an aquifer in the Overthrust Belt. The Mesaverde Formation was classified as a minor aquifer in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Cox (1976, Sheet 1) speculated that the Mesaverde Formation might yield a few tens of gallons per minute per well from sandstone. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.5 Everts Formation, Eagle Sandstone, and Telegraph Creek Formation

The Upper Cretaceous Everts Formation, Eagle Sandstone, and Telegraph Creek Formation (**pl. 6)** consist of massive to thin-bedded sandstone, mudstone, and shale (Love and Christiansen, 1985, Sheet 2). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Everts Formation might be a fair to poor (?) aquifer, the Eagle Sandstone was probably a fair aquifer, and the Telegraph Creek Formation might be a fair to poor aquifer in the Snake/Salt River Basin (**pl. 6**). Cox (1976, Sheet 1) speculated that sandstone in the formations might yield a few tens of gallons per minute per well. No data were located describing the physical and chemical hydrogeologic characteristics of the three lithostratigraphic units in the Snake/Salt River Basin.

7.3.6 Sohare Formation

The physical and chemical characteristics of the Sohare Formation in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Upper Cretaceous Sohare Formation (**pls. 5** and **6)** consists of lenticular gray and brown fine-grained sandstone interbedded with light- and dark-gray shale and siltstone with thin coal beds (Love, 1989; Love and others, 1992). The Sohare Formation is exposed in broad outcrops along the east side of Jackson Hole and is present on both flanks of the Gros Ventre Range to the south (**pl. 1**). Thickness varies from about 5,000 ft south of the Gros Ventre Range to an eroded edge just south of Yellowstone National Park (Love, 1989).

Few data are available describing the hydrogeologic characteristics of the Sohare Formation in the Snake/Salt River Basin. The Sohare Formation was classified as a marginal aquifer in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). No data were located describing the physical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

Chemical characteristics

The chemical characteristics of groundwater from the Sohare Formation in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Sohare Formation is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated as quantile values (**appendix E–3**).

Jackson Hole

The chemical composition of groundwater from the Sohare Formation in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituents are listed in **appendix E–3**. The TDS concentration (866 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–3**).

Concentrations of some properties and constituents in water from the well completed in the Sohare Formation in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No concentrations of constituents exceeded health-based standards, but one characteristic (TDS) exceeded USEPA aesthetic standards for domestic use (exceeded SMCL limit of 500 mg/L). One characteristic (SAR) exceeded the applicable State of Wyoming standard for agricultural use (exceeded WDEQ Class II standard of 8). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.3.7 Blind Bull Formation

The physical and chemical characteristics of the Blind Bull Formation in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Upper Cretaceous Blind Bull Formation (**pl. 4**) is present in the Snake/Salt River Basin. The Blind Bull Formation consists of partly conglomeratic sandstone, siltstone, claystone, coal, and bentonite (Rubey, 1973b; Oriel and Platt, 1980; Rubey and others, 1980). The Blind Bull Formation is a lateral stratigraphic equivalent to part of the Sohare Formation and Bacon Ridge Sandstone in the northern part of the Snake/Salt River Basin, and to part of the Hilliard Shale in the southern part of the Overthrust Belt, south of the Snake/Salt River Basin. The Hilliard Shale is located in the eastern and southern parts of the Overthrust Belt, and this shale unit becomes increasingly sandy northward and northwestward as it laterally grades into the Blind Bull Formation (Rubey, 1973b; Oriel and Platt, 1980; Rubey and others, 1980). Maximum thickness of the Blind Bull Formation in the Overthrust Belt ranges from 5,000 ft to as much as 9,186 ft (Rubey, 1973b; Schroeder, 1979, 1987; Oriel and Platt, 1980; Rubey and others, 1980).

Few data are available describing the hydrogeologic characteristics of the Blind Bull Formation in the Snake/Salt River Basin. Lines and Glass (1975, Sheet 1) speculated that sandstone in the Blind Bull Formation might be able to produce "small quantities of water." Two spring-discharge measurements for the formation (20 and 25 gal/min) were inventoried as part of this study (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Blind Bull Formation in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Blind Bull Formation is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt
The chemical composition of groundwater from the Blind Bull Formation in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations for available constituents are listed in **appendix E–5**. The TDS concentration (172 mg/L) from the spring indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Blind Bull Formation in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.8 Bacon Ridge aquifer

The physical and chemical characteristics of the Bacon Ridge aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

Saturated and permeable parts of the Upper Cretaceous Bacon Ridge Sandstone comprise the Bacon Ridge aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The Bacon Ridge Sandstone in the Grand Teton National Park area consists of tan to gray, thick-bedded, fine-grained sandstone containing abundant marine fossils interbedded with gray marine and brackish-water shale and siltstone (Love and others, 1992). Thin bentonite beds occur near the top and lower parts of the formation, and coal beds occur in parts of the formation. A 30-ft thick gold-bearing quartzite boulder conglomerate is present in the lower part of the formation and intertongues with marine strata. Reported maximum thickness of the Bacon Ridge Formation ranges from 1,000 to 1,500 ft (Love and others, 1992).

Few hydrogeologic data are available describing the hydrogeologic characteristics of the Bacon Ridge aquifer in the Snake/Salt River Basin. Hydrogeologic data describing the physical characteristics of the Bacon Ridge aquifer, including spring-discharge and well-yield measurements, are summarized on **plate 3**. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Bacon Ridge Formation might be a good aquifer (**pls. 5** and **6**). The Bacon Ridge Formation was classified as a marginal aquifer in the Wyoming Framework Water Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Cox (1976, Sheet 1) speculated that the Bacon Ridge Formation might yield a few tens of gallons per minute per well from sandstone.

Chemical characteristics

The chemical characteristics of groundwater from the Bacon Ridge aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Bacon Ridge aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–3**).

Jackson Hole
The chemical composition of the Bacon Ridge aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from one spring and one well. Individual constituents are listed in **appendix E–3**. TDS concentrations (216 mg/L in the spring sample and 547 mg/L in the well sample) indicated that waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**).

On the basis of the characteristics and constituents analyzed for, the quality of water from the spring issuing from the Bacon Ridge aquifer in JH was suitable for all uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from the well completed in the Bacon Ridge aquifer in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No concentrations of constituents exceeded health-based standards. Two characteristics exceeded USEPA aesthetic standards for domestic use: pH (value greater than the upper SMCL limit of 8.5) and TDS (concentration greater than SMCL of 500 mg/L). Two characteristics exceeded applicable State of Wyoming standards for agricultural-use standards: pH (value greater than upper WDEQ Class II standard of 9) and SAR (value exceeded WDEQ Class II standard of 8). The value of one characteristic (pH) exceeded a livestock-use standard (value exceeded upper WDEQ Class III standard of 8.5).

7.3.9 Cody confining unit

The Cody confining unit is composed of the Upper Cretaceous Cody Shale (**pls. 5** and **6**). Deposited in a marine environment, the Cody Shale consists of dull-gray shale interbedded with lesser amounts of gray siltstone and gray fine-grained slabby glauconitic sandstone (Love and others, 1992). Thickness of the Cody Shale ranges from 1,400 to 2,200 ft in the Jackson Hole area, 1,000 to 2,000 ft in the Green River and Hoback Basins, and 1,000 to 2,000 ft in the Gros Ventre Range (Love and others, 1992; Love and Love, 2000; Love, 2003a).

Because the lithostratigraphic unit is composed primarily of shale, the Cody Shale was classified as a confining unit by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein), and throughout the State in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Cody Shale are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as a confining unit was retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Despite being classified as a confining unit, the Cody confining unit likely can yield water locally in areas where discontinuous sandstone beds or zones with fractures (secondary permeability) are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Cox, 1976, Sheet 1). Cox (1976, Sheet 1) speculated that the sandstone beds probably would not yield more than a few gallons per minute per well. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.10 Frontier aquifer

The physical and chemical characteristics of the Frontier aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Frontier aquifer is composed of the Upper Cretaceous Frontier Formation (**pls. 4, 5,** and **6**). The Frontier Formation consists of interbedded white to brown fine- to medium-grained sandstone and dark gray shale with beds of abundant oyster fossils in the upper part of the formation (Oyster Ridge Sandstone Member), and coal and lignite beds in the lower part (individual members not shown on **plates. 4, 5,** and **6**). The Frontier Formation is not exposed above and to the west of the Absaroka thrust fault (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993) (**pl. 1**), where the Upper Cretaceous lower member of the Evanston Formation unconformably overlies the Lower Cretaceous Sage Junction Formation. The Frontier Formation was divided into additional members by Hale (1960), including the Dry Hollow, Allen Hollow Shale, Coalville, and Chalk Creek Members.

Frontier Formation thickness in the Snake/Salt River Basin varies by geographic area in the Snake/Salt River Basin. Thickness of the Frontier Formation ranges from 1,200 to 3,000 ft in the Overthrust Belt, 1,000 to 2,000 ft in the Northern Ranges, and is about 1,000 ft in Jackson Hole (Jobin, 1965; Love, 1974a, 1975b, 2001c, 2003a; Schroeder, 1974; Christiansen and others, 1978; Oriel and Platt, 1980; Rubey and others, 1980; Ahern and others, 1981; Oriel and Moore, 1985; Love and others, 1992; Love and Love 2000).

Previous investigators have classified the Frontier Formation as an aquifer and that definition is retained herein (**plates 4** and **5**). Robinove and Berry (1963, Plate 1) speculated that the Frontier Formation in the Bear River valley in the Overthrust Belt south of the Snake/Salt River Basin was "possibly an aquifer in areas." Lines and Glass (1975, Sheet 1) noted that sandstone aquifers in the Frontier Formation were capable of yielding moderate quantities of water and were the "best aquifers" in their "hydrogeologic division 5" (identified as being composed of Cretaceous shales and sandstones and shown on **plates 4, 5,** and **6**) in the Overthrust Belt. Similarly, the Frontier Formation was classified as a minor aquifer yielding moderate quantities of water by Ahern and others (1981, Figure II-7, and Table IV-1) in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). North of the Overthrust Belt, Cox (1976, Sheet 1) speculated that the Frontier Formation might yield a few tens of gallons per minute per well from sandstone; in addition, he noted that springs issuing from the formation in the Gros Ventre Range yield "a few gallons per minute." In the Wyoming Water Framework Plan, the Frontier Formation was classified as a minor aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5**, and **6**). All the investigators concluded that interbedded discontinuous sandstone beds compose the aquifer (Ahern and others, 1981; Lines and Glass, 1975, Sheet 1). Because sandstone beds compose the aquifer, permeability is primarily intergranular and related to the amount of cementation, except where fractured (Ahern and others, 1981). Hydrogeologic data (well yields) inventoried for the Frontier aquifer are shown on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Frontier aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Frontier aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–2**).

Northern Ranges

The chemical composition of the Frontier aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as three springs. Individual constituent concentrations are listed in **appendix E–2**. TDS concentrations indicated that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2**). Major-ion composition in relation to TDS for the three springs issuing from the Frontier aquifer is shown on a trilinear diagram (**appendix F–2, diagram D**). The TDS concentrations for the springs ranged from 80 to 416 mg/L, with a median concentration of 338 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Frontier aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA and State of Wyoming domestic, agricultural, or livestock water-quality standards.

7.3.11 Mowry confining unit

The Mowry confining unit is composed of the Upper Cretaceous Mowry Shale (**pls. 5** and **6**). The Mowry Shale consists of dark gray to black (weathers silvery gray), very hard, brittle, silicified, thin-bedded shale with some bentonite and secondarily silicified fine-grained sandstone (Love and others, 1992). Thickness of the Mowry Shale in the Gros Ventre Range ranges from 500 to 700 ft (Love, 1974a, 2001c; Love and Love, 1978, 2000; Love and others, 1992). Thickness of the Mowry Shale in Jackson Hole is about 650 ft

(Love, 2003a).

Because of the predominance of fine-grained lithologies such as shale, the Mowry Shale was classified as a confining unit by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein), and throughout the State in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Mowry Shale are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as a confining unit was retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Despite being classified as a confining unit, the Mowry confining unit likely can yield water locally in areas where discontinuous sandstone beds or zones with fractures (secondary permeability) are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Cox, 1976, Sheet 1). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.12 Aspen confining unit

The physical and chemical characteristics of the Aspen confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Aspen confining unit is composed of the Upper and Lower Cretaceous Aspen Shale (**pl. 4**). The Aspen Shale consists of interbedded light to dark gray shale, siltstone, and claystone with minor quartz-rich sandstone and porcellanite. Maximum thickness of the Aspen Shale in the Overthrust Belt ranges from less than 1,000 to 5,000 ft or more (Jobin, 1965, 1972; Pampeyan and others, 1967; Albee, 1968, 1973; Schroeder, 1969, 1973, 1974, 1976, 1979, 1987; Oriel and Platt, 1980; Schroeder and others, 1981; Oriel and Moore, 1985; Lageson, 1986). Maximum thickness of the Aspen Shale in the Teton Range is about 2,000 ft (Oriel and Moore, 1985). The Aspen Shale is laterally equivalent to the Mowry Shale (see **pls. 5** and **6**). Some beds are present that are transitional from the Aspen Shale to the lower part of the Blind Bull Formation (Rubey and others, 1980).

The Aspen Shale was identified as either "discontinuous aquifers with local confining beds" or a "locally utilized aquifer" in the Overthrust Belt by Ahern and others (1981, Figure II-7, and Table IV-1) (**pl. 4**). The investigators (Ahern and others, 1981, p. 61) also noted that the formation was composed primarily of low-permeability shale, and that "exploitable water yields were mainly from stray sands and fracture zones." In the Wyoming Water Framework Plan, the Aspen Shale was classified as a major aquitard (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**). Because shale is the predominant lithology, the Aspen Shale is classified as a confining unit herein (**pl. 4**); however, it is recognized that water can be obtained locally from the Aspen confining unit in areas where discontinuous sandstone beds or zones with fractures are present (Lines and Glass, 1975, Sheet 1; Ahern and others, 1981; Richter, 1981, Table IV-1). Lines and Glass (1975, Sheets 1, 2) noted that some domestic wells completed in permeable parts of the Aspen confining unit along the Snake River were abandoned because of hydrogen sulfide gas. Hydrogeologic data describing the Aspen confining unit in the Snake/Salt River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Aspen confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Aspen confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–3 and E–5**).

Jackson Hole

The chemical composition of the Aspen confining unit in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from two wells. Individual constituents are listed in **appendix E–3**. TDS concentrations measured in water from the wells (284 and 312 mg/L) indicated that both waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**).

Concentrations of some properties and constituents in water from the Aspen confining unit in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. The concentration of one constituent (fluoride) exceeded health-based standards (1 of 2 samples exceeded the USEPA MCL of 4 mg/L). Concentrations of two constituents exceeded USEPA aesthetic standards for domestic use: iron (1 of 2 samples exceeded SMCL of 300 μg/L) and fluoride (1 of 2 samples exceeded the SMCL of 2 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming domestic, agricultural, or livestock water-quality standards.

Overthrust Belt

The chemical composition of the Aspen confining unit in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as nine springs and one well. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS for springs issuing from the Aspen confining unit is shown on a trilinear diagram (**appendix F–5, diagram B**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram B**). TDS concentrations in the spring samples ranged from 107 to 228 mg/L, with a median of 195 mg/L. The TDS concentration in the well sample was 308 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Aspen confining unit in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.13 Sage Junction Formation

Present in the Overthrust Belt, the Upper Cretaceous Sage Junction Formation (**pl. 4**) is more than 3,000-ft thick and consists primarily of gray and tan siltstone, sandstone, and quartzite with minor amounts of porcellanite, limestone, conglomerate, and some coal beds (Rubey, 1973a, b; Lines and Glass, 1975, Sheet 1; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The formation is a lateral western stratigraphic equivalent to part of the Aspen Shale. The uppermost several hundred feet of the Sage Junction Formation may be equivalent in age to the lower part of the Upper Cretaceous Frontier Formation (Rubey, 1973b). The Sage Junction Formation is at least 3,375-ft thick above and to the west of the Absaroka thrust fault (**pl. 1**) and in the northwestern part of the Kemmerer area in the Bear River Basin south of the Snake/Salt River Basin (M'Gonigle and Dover, 1992). West and above the Absaroka thrust fault, the Upper Cretaceous lower member of the Evanston Formation unconformably overlies the Sage Junction Formation (M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993).

Changes in stratigraphic nomenclature between the western and eastern Cretaceous lithostratigraphic units occur at the Absaroka thrust fault in the Wyoming Overthrust Belt (Rubey, 1973b). Lithostratigraphic units located above and to the west of the Absaroka thrust, including the hanging wall of the fault, are the western units (Smiths, Thomas Fork, Cokeville, Quealy, and Sage Junction Formations), whereas those located below and to the east of the Absaroka thrust, including the footwall of the fault, are the eastern units (Bear River Formation and Aspen Shale) (**pl. 1; pl. 4**). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.14 Wayan Formation

The Upper and Lower Cretaceous Wayan Formation (**pl. 4**) consists of variegated mudstone, siltstone, and sandstone with minor porcellanite, bentonite, and coal (Oriel and Platt, 1980) (**pl. 4**). The formation is about 3,937-ft thick (Oriel and Platt, 1980). One spring discharge (10 gal/min) was inventoried for the formation as part of this study (**pl. 3**). No data were located describing the chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.15 Quealy Formation

The Upper Cretaceous Quealy Formation (**pl. 4**) consists of red and variegated pastel-tinted mudstone and minor interbedded pink, gray, and tan sandstone (Rubey, 1973b; Lines and Glass, 1975). The Quealy Formation thins eastward from about 1,100 ft in Idaho to about 500 ft in Wyoming (Oriel and Platt, 1980; Rubey and others, 1980). The Quealy Formation is the western stratigraphic equivalent of the middle to lower part of the Aspen Shale (Rubey, 1973b) (**plate 4**). No data were located describing the physical and chemical characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.16 Cokeville Formation

The Lower Cretaceous Cokeville Formation (**pl. 4**) consists of gray to tan fossiliferous sandstone, sandy siltstone, and light to dark gray claystone/mudstone with minor fossiliferous tan limestone; light gray, tan, and pink porcellanite; bentonite; and a few coal beds (Rubey, 1973b; Lines and Glass 1975; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The coal beds are located in the upper part of the Cokeville Formation (Rubey, 1973b). The Cokeville Formation thickens southeastward from about 850 ft in Idaho to about 3,000 ft in Wyoming (Oriel and Platt, 1980; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The upper part of the Cokeville Formation is the western stratigraphic equivalent of the lower part of the Aspen Shale, and the lower part of the formation is the western stratigraphic equivalent to the upper Bear River Formation (Rubey, 1973b) (**pl. 4**). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.17 Muddy Sandstone aquifer

The Muddy Sandstone aquifer is composed of the Lower Cretaceous Muddy Sandstone (**pls. 5** and **6**). The Muddy Sandstone consists of a 20- to 100-ft-thick rusty-brown to gray sandstone interbedded with black and gray siltstone and shale (Love, 1974a, 1975b, 2001c; Love and others, 1992; Love and Love, 2000). The formation is sometimes identified as a member of the underlying Thermopolis Shale (Love and others, 1992). The Muddy Sandstone aquifer is a major oil and gas reservoir in much of Wyoming. Because the lithostratigraphic unit is composed primarily of sandstone, the Muddy Sandstone was classified as an aquifer by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein), and throughout the State in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Muddy Sandstone are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as an aquifer was retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). In the subsurface, the Muddy Sandstone aquifer is confined from above by the Mowry confining unit and from below by the Thermopolis confining unit (**pls. 5** and **6**). No data were located describing the physical and chemical hydrogeologic characteristics of the hydrogeologic lithostratigraphic unit in the Snake/Salt River Basin.

7.3.18 Thermopolis confining unit

The Thermopolis confining unit is composed of the Lower Cretaceous Thermopolis Shale (**pls. 5** and **6**). The Thermopolis Shale primarily consists of black, flaky, soft shale (Love and others, 1992). The Thermopolis Shale is the northern and eastern stratigraphic equivalent to the Bear River Formation. Thickness of the Thermopolis Shale in the Gros Ventre Range ranges from 100 to 200 ft (Love and others, 1992; Love and Love, 2000; Love, 2001c, 2003c). Thickness of the Thermopolis Shale in the Overthrust Belt east of the Hoback fault ranges from 100 to 200 ft (Love and Love, 2000). North of Jackson Lake in the northern Teton Range, the Thermopolis Shale is only about 55-ft thick (Love and others, 1992). In the subsurface, the Thermopolis confining unit is overlain by the the Muddy Sandstone aquifer and underlain by the Cloverly aquifer (**pls. 5** and **6**).

Because the lithostratigraphic unit is composed primarily of shale, the Thermopolis Shale was classified as a confining unit by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein), and throughout the State in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Thermopolis Shale are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as a confining unit was retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Despite being classified as a confining unit, the Thermopolis confining unit likely can yield water locally in areas where discontinuous sandstone beds or zones with fractures (secondary permeability) are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Cox, 1976, Sheet 1). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.19 Bear River aquifer

The physical and chemical characteristics of the Bear River aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Lower Cretaceous Bear River Formation (**pl. 4**) consists of fissile black shale interbedded with brown fine-grained sandstone, and minor interbedded fossiliferous limestone and bentonite. Maximum thickness of the Bear River Formation in the Overthrust Belt ranges from less than 100 to about 1,800 ft (Jobin, 1965, 1972; Albee, 1968, 1973; Schroeder, 1973, 1974, 1976, 1979, 1981, 1987; Oriel and Platt, 1980; Schroeder and others, 1981; Oriel and Moore, 1985; Lageson, 1986; Love and others, 1992; Love, 2003c). Maximum thickness of the Bear River Formation in the Teton Range is about 1,000 ft (Oriel and Moore, 1985).

Previous investigators have classified the Bear River Formation as an aquifer, and that definition is retained herein (**pl. 4**). Berry (1955) identified the Bear River Formation as a potential aquifer in the Cokeville area in the Bear River Basin within the Overthrust Belt immediately south of the Snake/Salt River Basin. Robinove and Berry (1963, Plate 1) speculated that the Bear River Formation in the Bear River valley in the Overthrust Belt south of the Snake/Salt River Basin "possibly may yield small amounts of water." Lines and Glass (1975, Sheet 1) noted that "small quantities" of water were available from the discontinuous sandstone beds in the formation. In the Overthrust Belt, the Bear River Formation was identified as either "discontinuous aquifers with local confining beds" or a "minor aquifer" by Ahern and others (1981, Figure II-7, and Table IV-1) (**pl. 4**). Interbedded discontinuous sandstone beds compose the aquifer (Ahern and others, 1981; Lines and Glass, 1975, Sheet 1). In the Wyoming Water Framework Plan, the Bear River Formation was classified as a marginal aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**). Lines and Glass (1975, Sheets 1, 2) noted that some wells completed in the Bear River aquifer along the Snake River were abandoned because of hydrogen sulfide gas. Hydrogeologic data describing the Bear River aquifer in the Snake/Salt River Basin, including spring-discharge and well-yield measurements, and other hydraulic properties, are summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Bear River aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Bear River aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt

The chemical composition of aquifers in the Bear River aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as four springs and eight wells. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS for springs issuing from and wells completed in the Bear River aquifer is shown on two trilinear diagrams (**appendix F–5, diagrams C** and **D**). TDS concentrations indicated that waters from all four springs and six of eight wells were fresh (TDS concentrations less than or equal to 999 mg/L), and waters from two of eight wells were slightly saline (TDS concentration ranging from 1,000 to 2,999 mg/L) (**appendix E–5; appendix F–5, diagrams C** and **D**). The TDS concentrations for the springs ranged from 226 to 264 mg/L, with a median of 248 mg/L. The TDS concentrations for the wells ranged from 197 to 1,120 mg/L, with a median of 504 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from the Bear River aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from wells completed in the Bear River aquifer in the OTB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. Concentrations of two characteristics and two constituents exceeded USEPA aesthetic standards for domestic use: TDS (4 of 8 samples exceeded the SMCL of 500 mg/L), pH (1 of 8 samples exceeded the upper SMCL limit of 8.5), chloride (1 of 8 samples exceeded the SMCL of 250 mg/L), and fluoride (1 of 7 samples exceeded the SMCL of 2 mg/L).

Concentrations of some characteristics and constituents in water from wells completed in the Bear River aquifer exceeded State of Wyoming standards for agricultural and livestock use in the OTB. One characteristic and two constituents in the wells approached or exceeded applicable State of Wyoming standards for agricultural-use standards: chloride (2 of 8 samples exceeded WDEQ Class II standard of 100 mg/L), SAR (1 of 8 samples exceeded the WDEQ Class II standard of 8), and sulfate (1 of 8 samples exceeded the WDEQ Class II standard of 200 mg/L). The value of one characteristic (pH) exceeded the livestock-use standard (1 of 8 samples exceeded upper WDEQ Class III standard of 8.5).

7.3.20 Thomas Fork aquifer

The Thomas Fork aquifer is composed of saturated and permeable parts of the Lower Cretaceous Thomas Fork Formation (**pl. 4**). The Thomas Fork Formation consists of variegated, banded, red, purple, brown, and green mudstone and minor interbedded gray to tan sandstone (Rubey, 1973b; Lines and Glass 1975; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). In part, the sandstone is conglomeratic with sediments (pebbles and cobbles) as large as 4 inches in diameter, and the mudstone contains gray to brown limestone nodules as large as several inches in diameter (Rubey, 1973b). The formation is about 2,000-ft thick in the southwestern part of Star Valley (Rubey, 1973b; Oriel and Platt, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The formation merges to the south with and is lithologically indistinguishable from the upper part of the Early Cretaceous-age Kelvin Formation in northeastern Utah (Dover and M'Gonigle, 1993).

No data were located describing the physical and chemical characteristics of the Thomas Fork Formation in the Snake/Salt River Basin, but considerable insight into the hydrogeologic properties of the unit is provided by investigations in the Bear River Basin immediately to the south. Most information about the physical and chemical characteristics of the Thomas Fork aquifer was obtained through installation and subsequent testing of three wells completed in the aquifer to replace three springs as the water supply for the town of Cokeville in the Bear River Basin south of the Snake/Salt River Basin (Forsgren Associates, 1993b,c; TriHydro Corporation, 1993b, 2002, 2003). The Thomas Fork Formation is tentatively classified as an aquifer herein in the Snake/Salt River Basin based on these investigations. In fact, previous descriptions of the hydrogeologic characteristics of the Thomas Fork Formation were very limited. Lines and Glass (1975, Sheet 1) speculated that sandstone beds in the Thomas Fork Formation in the Overthrust Belt might yield "small quantities" of water to wells.

TriHydro Corporation (2002, p. 3-7) reported that sandstone beds composing the Thomas Fork aquifer in the Cokeville area typically were well cemented with calcite cement, and typically have poor intergranular porosity in "an unweathered and unfractured condition." Porosity and permeability were attributed to fractures in the sandstone beds composing the aquifer. Based on interpretation of aquifer tests conducted on the production wells, the investigators concluded that the Thomas Fork aquifer was a semiconfined, fracture-flow aquifer with primarily conduit flow. The investigators (TriHydro Corporation, 2002, p. 3-10) also conceptually described potential sources of recharge to the aquifer in the area. Potential sources of recharge identified were (1) streamflow losses and direct infiltration of precipitation and seepage to overlying lithostratigraphic units and subsequent movement of water in these units downward into the underlying Thomas Fork aquifer; and (2) direct infiltration of precipitation (rain and snow) on Thomas Fork aquifer outcrop areas.

7.3.21 Smiths Formation

The Lower Cretaceous Smiths Formation (**pl. 4**) consists of ferruginous black shale and interbedded tan, quartz-rich, very fine-grained sandstone. The black shale and tan sandstone are interbedded throughout the formation, but the upper unnamed member primarily is tan sandstone, and the lower unnamed member primarily is black shale (Rubey, 1973b; Rubey and others, 1980). The Smiths Formation thickens eastward from about 300 ft in Idaho to about 850 ft in Wyoming (Oriel and Platt, 1980; Rubey and others, 1980). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.22 Kootenai Formation

The Lower Cretaceous Kootenai Formation (**pl. 6**) consists of rusty thin-bedded sandstone, and grayish-red, soft claystone, white limestone, and chert-pebble conglomerate (Love and Christiansen, 1985, Sheet 2). Cox (1976, Sheet 1) speculated that sandstone in the Kootenai Formation probably would not yield more than a few gallons per minute per well. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.23 Cloverly aquifer

The Cloverly aquifer consists of saturated and permeable parts of the Lower Cretaceous Cloverly Formation in the Snake/Salt River Basin (**pls. 5** and **6**). The formation consists of two units in the Snake/Salt River Basin (Love and others, 1992). The upper unit is a 100- to 200-ft thick, olive-green, gray, and buff thin-bedded sandstone that commonly weathers to a rusty color and is informally known as the "rusty beds member." The lower unit is a 290- to 545-ft thick, variegated red, gray, lilac colored, and pink bentonitic claystone that commonly weathers to a "puffy surface;" thin beds of hard nodular dense cream-colored limestone also are present.

The Cloverly Formation is classified as an aquifer by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/ Salt River Basin (Bartos and others, 2012, and references therein), and southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Cloverly Formation was a fair to poor aquifer (**pls. 5** and **6**). The Cloverly Formation is classified as a minor aquifer in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of sandstones in the Cloverly Formation likely are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as an aquifer was tentatively retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Cox (1976) noted that sandstone in the unit probably would not yield more than a few gallons per minute per well. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.3.24 Gannett aquifer and confining unit

The physical and chemical characteristics of the Gannett aquifer and confining unit in the Snake/ Salt River Basin are described in this section of the report.

Physical characteristics

The Gannett aquifer and confining unit is composed of the Lower Cretaceous Gannett Group (**pl. 4**). The Gannett Group consists of red sandy mudstone, sandstone, and chert-pebble conglomerate. Some thin limestone and dark gray shale are present in the upper part of the unit, and the lower part is more conglomeratic. Reported thicknesses vary. Thickness of the Gannett Group decreases from about 2,953 ft in Idaho to about 787 ft in Wyoming (Oriel and Platt, 1980).

In some areas, the Gannett Group is mapped as separate formations or groups of formations. The Gannett Group was described in detail by Eyer (1969) and Furer (1967, 1970). The Gannett Group is composed of five formations (in descending order from top to bottom): Smoot Formation, Draney Limestone, Bechler Conglomerate, Peterson Limestone, and Ephraim Conglomerate.

The Smoot Formation of the Gannett Group was described as the unnamed upper redbed member until named by Eyer (1969). The Smoot Formation is composed of interbedded red mudstone and siltstone (Oriel and Platt, 1980). The Smoot Formation is absent in some local areas and is about 200-ft thick when combined with the underlying Draney Limestone (Oriel and Platt, 1980).

The Draney Limestone of the Gannett Group consists of dark to medium gray limestone, weathering light gray, very fine-crystalline to aphanitic limestone interbedded with dark gray calcareous shale and siltstone (Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980). The unit is about 200-ft thick when combined with the overlying Smoot Formation.

The Bechler Conglomerate of the Gannett Group is composed of red, red-gray, purple, and purple-gray, calcareous mudstone and siltstone, which becomes increasingly sandstone and chert-pebble conglomerate towards the west (Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980). A few thin limestone interbeds occur locally. The formation is about 1,300-ft thick.

The Peterson Limestone of the Gannett Group consists of light to medium gray and pastel-colored, weathering very light gray, very fine-crystalline limestone and pastel-colored calcareous mudstone (Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980). The unit is about 230-ft thick.

The basal Ephraim Conglomerate of the Gannett Group is composed of brick-red, red, orange-red, and maroon mudstone and siltstone; light gray, red, tan, and brown, crossbedded, coarse-grained calcareous to quartzitic sandstone; and red to brown, chert-pebble conglomerate. Thickness of the Ephraim Conglomerate decreases eastward from about 3,300 ft in Idaho to about 490 ft in Wyoming (Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980; M'Gonigle and Dover, 1992).

Permeability in the Gannett Group likely is small on a regional scale, and thus, in most areas the unit is capable of yielding only small quantities of water locally. However, more permeable water-bearing parts of the Gannett Group capable of yielding larger quantities of water are present in the conglomeratic formations (Bechler and Ephraim Conglomerates) and in areas where fractures and solution openings (secondary permeability) are present (Robinove and Berry, 1963; Lines and Glass, 1975, Sheet 1; Ahern and others, 1981, Table IV-1). In addition, sandstone beds in the lower part of the Gannett Group also may be permeable and water-bearing (Ahern and others, 1981, Table IV-1). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Smoot Formation and Ephraim Conglomerate might be poor to fair aquifers; the Draney Limestone might be a poor aquifer (?); the Bechler Conglomerate might be a poor aquifer; and the Peterson Limestone might be a fair to poor aquifer (?) in the Snake/Salt River Basin (**pl. 4**). Ahern and others (1981, Figure II-7) classified the Gannett Group as a series of "discontinuous aquifers with local confining units" in the Overthrust Belt and the adjacent Green River Basin (**pl. 4**). Glover (1990) considered the Ephraim Conglomerate of the Gannett Group (identified as a conglomerate near the base of the Gannett Group) to be a minor aquifer in the Evanston area in the Bear River valley in the Overthrust Belt to the south of the Snake/Salt River Basin. He also noted that aquifers in the Gannett Group were hydraulically isolated from the overlying Evanston aquifer (Hams Fork Conglomerate Member of the Evanston Formation), Wasatch aquifer, and Bear River alluvial aquifer. TriHydro Corporation (1993b, p. II-3) reported that the Ephraim Conglomerate produced about 10 gal/min during drilling of a test boring at the Spring Creek anticline near Cokeville in the Bear River Basin to the south of the Snake/Salt River Basin. In the Wyoming Water Framework Plan, the Gannett Group was classified as a marginal aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**).

Because the unit has low overall permeability, but has distinct zones and formations of higher permeability with potential to yield water to wells, the Gannett Group was classified as both an aquifer and confining unit herein (**pl. 4**). Few hydrogeologic data describing the Gannett aquifer and confining unit in the Snake/Salt River Basin are available, but spring-discharge and well-yield measurements inventoried as part of this study are shown on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Gannett aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Gannett aquifer and confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt

The chemical composition of groundwater in the Gannett aquifer and confining unit in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from three springs and one well. Individual constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS for springs issuing from the Gannett aquifer and confining unit is shown on a trilinear diagram (**appendix F–5, diagram E**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram E**). The TDS concentrations for the springs ranged from 141 to 228 mg/L, with a median of 208 mg/L. The TDS concentration for the well was 318 mg/L.

On the basis of the characteristics and constituents analyzed for, the quality of water from springs issuing from the Gannett aquifer and confining unit in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

On the basis of the characteristics and constituents analyzed for, the quality of water in the one well sample completed in the Gannett aquifer and confining unit in the OTB was suitable for most uses. One characteristic (pH) had a value outside the range for USEPA aesthetic standards for domestic use and WDEQ livestock-use standards (above upper SMCL and WDEQ Class III limit of 8.5). No characteristics or constituents had concentrations that exceeded State of Wyoming agricultural standards.

7.3.25 Morrison confining unit

The Upper Jurassic Morrison Formation comprises the Morrison confining unit in the Snake/Salt River Basin (**pls. 5** and **6**). The Morrison Formation consists of buff and gray sandstone interbedded with red, green, and gray siltstone and claystone (Love and others, 1992). Thickness of the formation ranges from 185 to 250 ft (Love and others, 1992).

The Morrison Formation is classified as a confining unit, an aquifer, or both, by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), and southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Morrison Formation was probably a poor aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The Morrison Formation is classified as a minor aquifer in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Morrison Formation generally are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as a confining unit was tentatively retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Cox (1976, Sheet 1) noted that the unit probably would not yield more than a few gallons per minute per well in northwestern Wyoming. No data were located in the Snake/Salt River Basin describing the physical and chemical characteristics of the hydrogeologic unit.

7.3.26 Ellis Group

In the Yellowstone Volcanic Area in the Snake/Salt River Basin, the Middle Jurassic Ellis Group is composed of three different formations—the Swift, Rierdon, and Sawtooth Formations (Love and Christiansen, 1985, Sheet 2) (**pl. 1**; **pl. 6**). The Swift Formation consists of calcareous, glauconitic sandstone and sandy limestone. The Rierdon Formation consists of mudstone, siltstone, shale, and basal limestone. The Sawtooth Formation consists of redbeds and limestone. No data were located describing the physical and chemical characteristics of the Ellis Group in the Snake/Salt River Basin.

7.3.27 Sundance aquifer

The Middle and Upper Jurassic Sundance Formation comprises the Sundance aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The formation consists of two lithologic units in the Snake/Salt River Basin. The upper unit consists of glauconitic gray, buff, and green very calcareous sandstone with a few thin shale beds and very fossiliferous limestone beds (Love and others, 1992). Thickness of the upper unit ranges from 75 to 140 ft. The lower unit consists of gray calcareous plastic to splintery shale, clayey limestone, hard oolitic limestone, and one or more zones of red, soft, plastic shale (Love and others, 1992). The lower unit is marine in origin and is highly fossiliferous. Thickness of the lower unit ranges from 400 to 550 ft.

Cox (1976, Sheet 1) speculated that the unit may yield a few gallons per minute per well from sandstone and from fractures and solution channels in limestone. No data were located in the Snake/Salt River Basin describing the physical and chemical characteristics of the hydrogeologic unit.

7.3.28 Stump Formation

The physical and chemical characteristics of the Stump Formation in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Upper to Middle Jurassic Stump Formation (**pl. 4**) consists of interbedded light to dark green, green-gray, glauconitic, fine-grained sandstone, siltstone, and limestone (Lines and Glass, 1975; Oriel and Platt, 1980; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Pipiringos and Imlay (1979) divided the Stump Formation into two members—the Upper Jurassic Redwater Member and the Middle Jurassic Curtis Member (individual members not shown on Plate 4). The Stump Formation ranges in thickness from 92 ft to at least 400 ft in the Overthrust Belt area, and thins irregularly to the north and east from the thickest section in southeastern Idaho (Pipiringos and Imlay, 1979; Oriel and Platt, 1980; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). The upper member of the Stump Formation is similar to the silty to sandy facies of the Redwater Member of the Sundance Formation eastward in Wyoming, whereas the lower member is similar to the Curtis Formation in the San Rafael Swell area of central Utah (Pipiringos and Imlay, 1979).

The Redwater Member of the Stump Formation consists of two lithologic units (Pipiringos and Imlay, 1979). The upper lithologic unit is composed of gray, green-gray, nearly white, glauconitic, thin- to thick-bedded, crossbedded sandstone with minor interbeds of sandy siltstone, clayey siltstone, and oolitic, sandy limestone, which locally contains chert pebbles, belemnite fossils, and ammonite fossils. The lower lithologic unit is composed of yellow-gray to brown, glauconitic siltstone and claystone, which is locally sandy and contains belemnite fossils.

The Curtis Member of the Stump Formation consists of two lithologic units (Pipiringos and Imlay, 1979). The upper lithologic unit is composed of green-gray to olive-green, soft, flaky to fissile claystone with minor thin interbeds of sandstone and oolitic, fossiliferous limestone. The lower lithologic unit is composed of green-gray to brown-gray, glauconitic, thin- to thick-bedded, ripple-marked, crossbedded, fine- to very fine-grained sandstone (some silty and medium-grained sandstone).

Little information is available describing the hydrogeologic characteristics of the Stump Formation. Robinove and Berry (1963, Plate 1) speculated that the Stump Formation was likely to yield small quantities of groundwater to wells in the Bear River valley in the Overthrust Belt south of the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Stump Formation was a fair to poor (?) aquifer in the Snake/Salt River Basin (**pl. 4**). Lines and Glass (1975, Sheet 1) noted that rocks in the Stump Formation in the Overthrust Belt were relatively impermeable and in most areas were probably capable of yielding only small quantities of water. Ahern and others (1981, Figure II-7, Table IV-1) classified the Stump Formation as a confining unit [aquitard] or poor aquifer (**pl. 4**). Few hydrogeologic data are available describing the Stump Formation, but well-yield and spring-discharge measurements inventoried for the lithostratigraphic unit in the Snake/Salt River Basin are summarized in **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Stump Formation in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Stump Formation is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–3** and **E–5**).

Jackson Hole
The chemical composition of the Stump Formation in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental

water sample from one spring. Individual constituents are listed in **appendix E–3**. The TDS concentration (245 mg/L) indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Stump Formation in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Stump Formation in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–5**. The TDS concentration (241 mg/L) indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Stump Formation in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.29 Preuss Sandstone or Redbeds

The Middle Jurassic Preuss Sandstone or Redbeds (**plate 4**) consists of interbedded purple, maroon, dull red, purple-gray, and red-gray, siltstone, sandy siltstone, silty claystone, and claystone with minor interbedded halite (rock salt), alum, and gypsum locally present in irregular zones (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey and others, 1980; M'Gonigle and Dover, 1992; Dover and M'Gonigle, 1993). Beds of red, gray, and tan, fine-grained, thin-bedded and regular-bedded sandstone also are present. Formation thickness decreases eastward from about 1,640 ft in Idaho to 360 ft in Wyoming (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey and others, 1980). The Preuss Sandstone or Redbeds are overlain by the Stump Formation and underlain by the Twin Creek Limestone (**pl. 4**).

Little information is available describing the hydrogeologic characteristics of the Preuss Sandstone or Redbeds. Robinove and Berry (1963, Plate 1) speculated that the Preuss Sandstone or Redbeds were likely to yield small quantities of groundwater to wells in the Bear River valley in the Overthrust Belt to the south of the Snake/Salt River Basin,. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Preuss Sandstone or Redbeds likely were a poor aquifer (?) in the Snake/Salt River Basin (**pl. 4**). Lines and Glass (1975, Sheet 1) noted that rocks in the Preuss Sandstone or Redbeds were relatively impermeable and in most areas were probably capable of yielding only small quantities of water. Ahern and others (1981, Figure II-7, Table IV-1) classified the formation as a confining unit [aquitard] or poor aquifer (**pl. 4**). No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

In outcrop and shallow groundwater areas, bedded halite (rock salt) in the lower part of the formation has been removed by dissolution (Imlay, 1952). In areas where evaporite beds have been removed by dissolution, breccia zones and collapse structures may have formed and consequently, may have increased permeability.

7.3.30 Twin Creek aquifer

The physical and chemical characteristics of the Twin Creek aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Twin Creek aquifer is composed of the Middle Jurassic Twin Creek Limestone (**pl. 4**). The Twin Creek Limestone consists of green-gray argillaceous (shaly) limestone and calcareous siltstone. Thickness of the formation decreases eastward from about 3,300 ft in Idaho to about 440 ft in Wyoming (Imlay, 1967; Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980;

M'Gonigle and Dover, 1992). The formation is as much as 2,900-ft thick above and to the west of the Absaroka thrust fault (WSGS Plate 1?). Thickness of the Twin Creek Limestone below and to the east of the Absaroka thrust fault in the Kemmerer area in the Bear River Basin south of the Snake/Salt River Basin ranges from 800 to 1,000 ft (M'Gonigle and Dover, 1992). The Twin Creek Limestone was deposited in a Jurassic seaway marine environment, as reflected by the presence of pelecypod fossils such as *Gryphaea* (Imlay, 1967). Imlay (1967) defined and described seven members of the Twin Creek Formation in the Overthrust Belt of Wyoming-Idaho-Utah. These members are, from youngest (top) to oldest (bottom): Giraffe Creek Member, Leeds Creek Member, Watton Canyon Member, Boundary Ridge Member, Rich Member, Sliderock Member, and Gypsum Spring Member (individual members not shown on Plate 4).

The Giraffe Creek Member of the Twin Creek Limestone consists of yellow-gray, green-gray, and pink-gray, silty to sandy, ripple-marked, thin-bedded limestone and sandstone with minor thick interbeds of oolitic sandy limestone. Sand and glauconite content increases to the west, and the Giraffe Creek Member of the Twin Creek Limestone grades upward into red, soft siltstone at the base of the Preuss Sandstone or Redbeds. Thickness decreases eastward and northward from 295 to 25 ft (Imlay, 1967).

The Leeds Creek Member of the Twin Creek Limestone consists of light gray, dense, shaly, soft limestone, which weathers into slender splinters, and minor interbeds of oolitic silty or sandy, ripple-marked limestone. Clay content increases to the northeast in Idaho and Wyoming and to the south in Utah. The Leeds Creek Member is the least resistant member of the Twin Creek Limestone and commonly forms valleys in outcrop areas. The Leeds Creek Member of the Twin Creek Limestone grades upward into the harder, silty to sandy, basal limestone of the overlying Giraffe Creek Member. Thickness decreases eastward from about 1,600 to 260 ft (Imlay, 1967).

The Watton Canyon Member of the Twin Creek Limestone consists of gray, compact, dense, brittle, medium- to thin-bedded limestone, which forms prominent cliffs and ridges. The basal unit of the Watton Canyon Member generally is massive and oolitic, and some oolitic limestone interbeds occur throughout the unit. The upper part of the Watton Canyon Member grades upward into the shaly, soft basal limestone of the overlying Leeds Creek Member and contains pelecypod fossils. Thickness of the Watton Canyon Member decreases eastward from about 400 to 60 ft (Imlay, 1967).

The Boundary Ridge Member of the Twin Creek Limestone consists of red, green, and yellow, soft siltstone with interbedded silty to sandy or oolitic limestone. The Boundary Ridge Member grades eastward into red, gypsiferous, soft siltstone and claystone, and grades westward into cliff-forming, oolitic to dense limestone with minor interbedded red siltstone. The Boundary Ridge Member is overlain by the cliff-forming, basal limestone of the Watton Canyon Member. Thickness decreases eastward from about 285 to 30 ft (Imlay, 1967).

The Rich Member of the Twin Creek Limestone consists of gray, shaly limestone that is very soft at the base; clay content increases to the north, and the upper part grades into the basal hard sandy limestone or red, soft siltstone of the Boundary Ridge Member of the Twin Creek Limestone. Pelecypod and cephalopod fossils are present. Thickness of the Rich Member decreases eastward from 500 to 40 ft (Imlay, 1967).

The Sliderock Member of the Twin Creek Limestone consists of gray-black, medium- to thin-bedded limestone with oolitic basal beds, and commonly forms a low ridge between adjacent members. Pelecypod and cephalopod fossils are present. Thickness of the Sliderock Member decreases eastward from 285 to 20 ft (Imlay, 1967).

The Gypsum Spring Member of the Twin Creek Limestone consists of red to yellow, soft siltstone and claystone, interbedded with brecciated, vuggy, or chert-bearing limestone. In Wyoming, a basal unit of brecciated limestone is present and grades eastward into thick, massive gypsum deposits.

The chert-bearing limestone thickens westward from a few feet thick in Wyoming to a thick, cliff-forming unit in Idaho. Locally, the top bed of the Gypsum Spring Member is a green tuff. Thickness of the Gypsum Spring Member decreases eastward from 400 to 12 ft (Imlay, 1967). In some areas of Wyoming, including parts of the Snake/Salt River Basin, the Gypsum Spring Member of the Twin Creek Limestone has been elevated to formation rank and is referred to as the Gypsum Spring Formation (Love and others, 1993).

The Twin Creek Limestone is classified as an aquifer or potential aquifer by previous investigators and that classification is retained herein (**pl. 4**). Robinove and Berry (1963, Plate 1) speculated that the Twin Creek Limestone was likely to yield small quantities of groundwater to wells in the Bear River valley in the Overthrust Belt to the south of the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Twin Creek Limestone was a poor aquifer (?) in the Snake/Salt River Basin (**pl. 4**). Lines and Glass (1975, Sheet 1) noted that permeability in the upper part of the Twin Creek Limestone likely was low compared to the lower part and thus, the formation likely would yield small quantities of water to wells completed in the upper part of the unit. The investigators noted that limestone in the lower part of the Twin Creek Limestone is brecciated and honeycombed; thus, wells completed in the lower part of the formation were more likely to yield moderate quantities of water (Lines and Glass, 1975, Sheet 1). In the Wyoming Water Framework Plan, the Twin Creek Limestone was classified as a minor aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**). Hydrogeologic data describing the Twin Creek aquifer, including spring-discharge measurements and other hydraulic properties, are summarized on **pl. 3**.

The Twin Creek aquifer likely is in hydraulic connection with the underlying Nugget aquifer (Lines and Glass, 1975, Sheet 1; Ahern and others, 1981). In fact, Lines and Glass (1975, Sheet 1) noted that few springs issue from the lower part of the Twin Creek Limestone, possibly because the overlying unit may be in hydraulic connection with, and "drain into" the underlying Nugget aquifer. Clarey (2011) speculated that groundwater from the Gypsum Spring Member in areas where gypsum deposits are present may have the potential for calcium-sulfate-type waters and large TDS concentrations.

Chemical characteristics

The chemical characteristics of groundwater from the Twin Creek aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Twin Creek aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2, E–5,** and **E–6**).

Northern Ranges

The chemical composition of the Twin Creek aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–2**. The TDS concentration (256 mg/L) indicated that the water was fresh (concentration less than or equal to 999 mg/L) (**appendix E–2**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Twin Creek aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Twin Creek aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as 10 springs. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS concentrations for springs issuing from the Twin Creek aquifer is shown on a trilinear diagram (**appendix F–5, diagram F**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram F**). The TDS concentrations for the springs ranged from 133 to 326 mg/L, with a median of 219 mg/L. On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Twin Creek aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Star Valley
The chemical composition of the Twin Creek aquifer in the Star Valley (SV) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–6**. The TDS concentration (614 mg/L) indicated that waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–6**).

Concentrations of some properties and constituents in water from a spring issuing from the Twin Creek aquifer in the SV approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: TDS (exceeded SMCL limit of 500 mg/L) and sulfate (exceeded SMCL of 250 mg/L). One constituent in the spring approached or exceeded applicable State of Wyoming standards for agricultural-use standards: sulfate (exceeded WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.3.31 Gypsum Spring confining unit

The physical and chemical characteristics of the Gypsum Spring confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Gypsum Spring confining unit is composed of the Middle Jurassic Gypsum Spring Formation (**pls. 5** and **6**). The Gypsum Spring Formation consists of dark-red soft shale, underlain by and interbedded with slabby gray dolomite and white gypsum. In most outcrop areas, gypsum in the formation has been leached, leaving lithified carbonate breccia that forms rounded cliffs (Love and others, 1992). Thickness of the formation ranges from 50 to 150 ft, depending on amount of leaching of gypsum (Love and others, 1992).

The Gypsum Spring Formation is classified as a confining unit, aquifer, or both by previous investigators in the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), and southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Gypsum Spring Formation was a poor aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). The Gypsum Spring Formation was classified as a marginal aquifer in the Wyoming Water Framework Plan (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because of lithologic characteristics of the Gypsum Spring Formation in the study area (described above), the lithostratigraphic unit was tentatively classified as a confining unit in the Snake/Salt River Basin (**pls. 5** and **6**). One spring discharge was inventoried as part of this study for the Gypsum Spring confining unit in the Snake/Salt River Basin (**pl. 3**).

Chemical characteristics

The chemical characteristics of groundwater from the Gypsum Spring confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Gypsum Spring confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–2**).

Northern Ranges
The chemical composition of the Gypsum Spring confining unit in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–2**. The TDS concentration (2,190 mg/L) indicated that the water was slightly saline (TDS concentration ranging from1,000 to 2,999 mg/L) (**appendix E–2**).

Concentrations of some properties and constituents in water from the spring issuing from the Gypsum Spring confining unit in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use and State of Wyoming standards for agricultural use: TDS (exceeded SMCL limit of 500 mg/L and WDEQ Class II standard of 2,000 mg/L) and sulfate (exceeded SMCL of 250 mg/L and WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.3.32 Nugget aquifer

The physical and chemical characteristics of the Nugget aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Nugget aquifer is composed of the Triassic (?) to Jurassic (?) Nugget Sandstone (**pls. 4**, **5**, and **6**). The Nugget Sandstone consists of tan to pink, crossbedded, well-sorted, quartz-rich sandstone (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; Rubey and others, 1980; Love and others, 1992). The Nugget Sandstone has been interpreted as deposited as an eolian (wind-blown) sand dune sequence from a desert or a beach environment. Reported maximum thickness of the Nugget Sandstone in the Northern Ranges (Teton and Gros Ventre Ranges) ranges from about 100 to 400 ft (Pampeyan and others, 1967; Oriel and Moore, 1985; Love and others, 1992; Love, 2001a,b,c). Reported maximum thickness of the Nugget Sandstone in the Overthrust Belt ranges from about 250 to 984 ft (Jobin, 1965, 1972; Pampeyan and others, 1967; Schroeder, 1969, 1972, 1973, 1974, 1976, 1979, 1981; Albee, 1968, 1973; Albee and Cullins, 1975; Oriel and Platt, 1980; Schroeder and others, 1981; Love and others, 1992; Love, 2003c).

The Nugget Sandstone is classified as an aquifer by all investigators and that classification is retained herein (**pls. 4**, **5,** and **6**). Robinove and Berry (1963, Plate 1) speculated that the Nugget Sandstone was likely to yield small quantities of groundwater to wells in the Bear River valley in the Overthrust Belt to the south of the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Nugget aquifer was a fair to good aquifer in the Snake/Salt River Basin (**pls. 4**, **5,** and **6**). Lines and Glass (1975, Sheet 1) considered the Nugget Sandstone to be the "best aquifer" in their "hydrogeologic division 4" (identified as being composed of Jurassic- and Cretaceous-age sandstone and limestone and shown on **pls. 4** and **5**) in the Overthrust Belt. The investigators (Lines and Glass, 1975, Sheet 1) reported that the Nugget aquifer was capable of yielding moderate to large quantities of water where "outcrop or recharge areas are large, where bedding is continuous and not offset by faults, and in topographic lows where large thickness of sandstone is saturated." Furthermore, the investigators (Lines and Glass, 1975, Sheet 1) noted that few springs issue from the lower part of the Twin Creek Limestone, possibly because the overlying unit may be in hydraulic connection with, and "drain into" the underlying Nugget aquifer. Springs commonly issue from the Nugget aquifer in the Overthrust Belt (Lines and Glass, 1975, Sheet 1) (also see **pl. 3**). In the Wyoming Water Framework Plan, the Nugget Sandstone was classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Spring-discharge and well-yield measurements for the Nugget aquifer in the Snake/Salt River Basin inventoried as part of this study are summarized in **plate 3**.

Ahern and others (1981, Figure II-7, and Table IV-1) classified the Nugget Sandstone as a major aquifer in the Overthrust Belt and the adjacent Green River Basin (**pls. 4** and **5**). The Nugget aquifer was considered to be part of an aquifer system, identified as the Nugget aquifer system, composed of the overlying Twin Creek Limestone and the underlying Ankareh Formation and Thaynes Limestone in the Overthrust Belt (**pl. 4**). The investigators noted that porosity and permeability in the Nugget aquifer were "good," especially in the crossbedded upper part. The investigators also speculated that smaller transmissivities for the Nugget aquifer in the adjacent Green River Basin may be attributable to increased lithostatic pressure (deeper burial) and decreased fracture occurrence.

Clarey (2011) noted that the upper part of the Nugget Sandstone in some areas of the Overthrust Belt has calcite (calcium carbonate) cement with slightly increased permeability, and that the lower part of the formation has siliceous (quartz) cement with decreased permeability. The investigator reported that this "dual cementation feature" of the Nugget Sandstone has been observed in an oilfield production well located to the northeast of Evanston in Uinta County, Wyoming.

Chemical characteristics

The chemical characteristics of groundwater from the Nugget aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Nugget aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt

The chemical composition of groundwater in the Nugget aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as 10 springs and 1 well. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS concentrations for springs issuing from the Nugget aquifer is shown on a trilinear diagram (**appendix F–5, diagram G**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram G**). The TDS concentrations in the spring samples ranged from 30.0 to 388 mg/L, with a median of 106 mg/L. The TDS concentration in the well sample was 269 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Nugget aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.33 Chugwater aquifer and confining unit

The physical and chemical characteristics of the Chugwater aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Chugwater aquifer and confining unit is composed of the Upper and Lower Triassic-age Chugwater Formation (**pls. 5** and **6**). The Chugwater Formation is composed of four members (Love and others, 1992) (individual members not shown on Plates 5 and 6). The uppermost unit, the Popo Agie Member, consists of ocher and purple claystone, red shale, lenticular purple limestone-pellet conglomerate, and red siltstone, ranging in thickness from 75 to 300 ft. The next lower unit, the Crow Mountain Sandstone Member, consists of red to salmon-pink soft porous sandstone containing large rounded quartz grains in a finer matrix, ranging in thickness from 50 to 100 ft. The next lower unit, the Alcova Limestone Member, consists of gray and purple thin-bedded hard limestone and dolomite with interbeds of white gypsum, ranging in thickness from 10 to 60 ft. The lowermost unit is the Red

Peak Member, which consists of red gypsiferous siltstone and very fine grained sandstone containing some red shale partings, ranging in thickness from 800 to 1,275 ft.

The Chugwater Formation is classified as a confining unit, an aquifer, or both, by previous investigators (**pls. 5** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Chugwater Formation was probably a fair to poor aquifer (?) in the Snake/Salt River Basin (**pls. 5** and **6**). In the eastern Gros Ventre Range, the Chugwater Formation was combined by Mills (1989) and Mills and Huntoon (1989) with the underlying Dinwoody and Phosphoria Formations into a single confining unit that overlies and confines the underlying Tensleep aquifer (**pl. 5**). In the adjacent Wind River and Bighorn Basins east of the Snake/Salt River Basin (Bartos and others, 2012, and references therein), and southeast in the Green River Basin (Bartos and Hallberg, 2010, and references therein), the Chugwater Formation was classified as both aquifer and confining unit (**pls. 5** and **6**). The Chugwater Formation is classified as either a marginal aquifer or major aquitard in the Wyoming Water Framework Plan, depending upon area of occurrence (WWC Engineering and others, 2007, Figure 4-9) (**pls. 5** and **6**). Because lithologic characteristics of the Chugwater Formation generally are similar in all Wyoming structural basins, classification of the lithostratigraphic unit as both an aquifer and confining unit was tentatively retained herein for the Snake/Salt River Basin (**pls. 5** and **6**). Cox (1976, Sheet 1) noted that the unit probably would not yield more than a few gallons per minute per well in northwestern Wyoming. Few hydrogeologic data are available describing the Chugwater aquifer and confining unit in the Snake/Salt River Basin, but two well-yield measurements were inventoried as part of this study and are presented on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Chugwater aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Chugwater aquifer and confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–2**).

Northern Ranges

The chemical composition of the Chugwater aquifer and confining unit in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from two wells. Individual constituents are listed in **appendix E–2**. The TDS concentrations (153 and 1,340 mg/L) indicated that the waters were fresh and slightly saline (TDS concentrations less than or equal to 999 mg/L, and TDS concentrations greater than or equal to 1,000 and less than or equal to 2,999 mg/L, respectively).

Concentrations of some properties and constituents in water from the Chugwater aquifer and confining unit in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: TDS (1 of 2 samples exceeded SMCL limit of 500 mg/L) and sulfate (1 of 2 samples exceeded SMCL of 250 mg/L). One constituent approached or exceeded applicable State of Wyoming standards for agricultural-use standards: sulfate (1 of 2 samples exceeded WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.3.34 Ankareh aquifer

The physical and chemical characteristics of the Ankareh aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Ankareh aquifer is composed of the Upper Triassic Ankareh Formation (**pl. 4**). The Ankareh

Formation consists of red and maroon shale and pale purple limestone with minor white to red, fine-grained, quartz-rich sandstone; thickness of the formation increases eastward from about 460 ft in Idaho to about 920 ft in Wyoming (Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). In central Wyoming, the Ankareh Formation is the stratigraphic equivalent of the upper part of the Chugwater Group or Formation (including the Red Peak Member, Alcova Limestone Member, unnamed redbeds of interbedded siltstone and sandstone, and Popo Agie Member of the Chugwater Group or Formation) (Kummel, 1954). The sandstone may correlate westward to the Timothy Sandstone Member of the Thaynes Limestone, and the limestone may correlate westward to the Portneuf Limestone Member of the Thaynes Limestone (Kummel, 1954). Redbeds present below the thin limestone or sandstone in the Ankareh Formation may correlate westward to the Lanes Tongue of the Ankareh Formation (Kummel, 1954).

Previous investigators have defined the Ankareh Formation as an aquifer, and that definition is tentatively retained herein (**pl. 4**). Robinove and Berry (1963, Plate 1) speculated that the Ankareh Formation was likely to yield small quantities of groundwater to wells in the Bear River valley to the south of the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Ankareh Formation was probably a poor aquifer in the Snake/Salt River Basin (**pl. 4**). Lines and Glass (1975, Sheet 1) noted that rocks in the Ankareh Formation were relatively impermeable in most areas, but that the unit was probably capable of yielding small quantities of water locally. Ahern and others (1981, Figure II-7, and Table IV-1) defined the Ankareh Formation as a minor aquifer or minor regional aquifer (locally confining) in the Overthrust Belt (**pl. 4**). Spring-discharge measurements for the Ankareh aquifer in the Snake/Salt River Basin inventoried as part of this study are summarized in **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Ankareh aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Ankareh aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2 and E–5**).

Northern Ranges

The chemical composition of the Ankareh aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–2**. The TDS concentration (256 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–2**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Ankareh aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Ankareh aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs. Individual constituents are listed in **appendix E–5**. The TDS concentrations (263 and 364 mg/L) indicated that waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Ankareh aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.35 Thaynes aquifer

The physical and chemical characteristics of the Thaynes aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Thaynes aquifer is composed of saturated and permeable parts of the Upper and Lower Triassic Thaynes Limestone (**pl. 4**). The Thaynes Limestone consists of gray limestone and brown-weathering, gray, calcareous siltstone with abundant dark gray shale and abundant limestone in the lower part of the formation (Lines and Glass, 1975; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). Thickness of the Thaynes Limestone in the Overthrust Belt ranges from about 250 to 1,640 ft (Jobin, 1965, 1972; Pampeyan and others, 1967; Albee, 1968, 1973; Schroeder, 1969, 1973, 1979, 1981, 1987; Albee and Cullins, 1975; Oriel and Platt, 1980; Schroeder and others, 1981; Oriel and Moore, 1985; Lageson, 1986; Love and others, 1992). Thickness of the Thaynes Limestone in the Teton Range ranges from about 110 to 1,640 ft (Pampeyan and others, 1967; Oriel and Moore, 1985).

Kummel (1954) defined several members of the Thaynes Limestone and the interfingering Ankareh Formation, which the investigator considered a member of the Thaynes Limestone (individual members not shown on Plate 4). The Timothy Sandstone Member is the uppermost member of the Thaynes Limestone and is missing at some locations. The Timothy Sandstone Member consists of red siltstone, shale, and sandstone at Hot Springs along Indian Creek in southeastern Idaho and rapidly thins eastward into Wyoming. In adjacent Idaho, the Timothy Sandstone Member was removed by Trimble (1982) as a member of the Thaynes Limestone and was elevated to formation rank because of its "nonmarine origin." The Portneuf Limestone Member of the Thaynes Limestone consists of olive-gray, massive limestone and olive-light tan calcareous siltstone. The Lanes Tongue of the Thaynes Limestone consists of red, interbedded shale and siltstone. The redbeds member is similar to the overlying Ankareh Formation. The upper calcareous siltstone member consists of light tan, thin- to massively-bedded, silty limestone and calcareous siltstone. The middle shale member of the Thaynes Limestone consists of black shale and shaly limestone with cephalopod, ammonite, and pelecypod fossils. The lower shale member of the Thaynes Limestone is composed of dark gray, silty limestone. The lower limestone member of Thaynes Limestone consists of gray-blue to gray (weathers gray), massive limestone with cephalopod fossils.

Previous investigators generally have defined the Thaynes Limestone as an aquifer and that definition is retained herein (**plate 4**). Robinove and Berry (1963, Plate 1) speculated that the Thaynes Limestone was likely to yield small quantities of groundwater to wells in the Bear River valley to the south of the Snake/Salt River Basin. Lines and Glass (1975, Sheet 1) considered the Thaynes Limestone to be the "best aquifer" in their "hydrogeologic division 3" (identified as being composed of Triassic and Permian siltstones and limestones and shown on **plate 4**) in the Overthrust Belt. Ahern and others (1981, Figure II-7, and Table IV-1) defined the Thaynes Limestone as a major aquifer or regional aquifer in the Overthrust Belt. In contrast to these previous investigators, the Wyoming Water Planning Program (1972, Table III-2) speculated that the Thaynes Limestone was a confining unit in the Snake/Salt River Basin (**pl. 4**). Limestone in the Thaynes aquifer likely yields moderate quantities of water to wells; yields are greatest in areas with bedding-plane partings and where secondary permeability in the form of fractures or solution openings, or both, has developed (Lines and Glass, 1975, Sheet 1; Ahern and others, 1981, Figure II-7, and Table IV-1). Spring-discharge measurements and other hydraulic properties for the Thaynes aquifer in the Snake/Salt River Basin inventoried as part of this study are summarized in **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Thaynes aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Thaynes aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt
The chemical composition of groundwater in the Thaynes aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as six springs. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major-ion composition in relation to TDS concentrations for the six springs is shown on a trilinear diagram (**appendix F–5, diagram H**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; Appendix F–5, diagram H**). The TDS concentrations for the springs ranged from 89.0 to 281 mg/L, with a median of 186 mg/L. On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Thaynes aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.3.36 Woodside confining unit

The physical and chemical characteristics of the Woodside confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Woodside confining unit is composed of the Lower Triassic Woodside Shale (**pl. 4**). The Woodside Shale consists of interbedded red siltstone and shale with minor sandstone and gray limestone interbeds; thickness increases eastward across the Overthrust Belt from about 390 ft in Idaho to about 650 ft in Wyoming (Kummel, 1954; Lines and Glass, 1975, Sheet 1; Oriel and Platt, 1980; M'Gonigle and Dover, 1992). The Woodside Formation overlies the Dinwoody Formation and is overlain by the Thaynes Limestone in the Overthrust Belt in the Snake/Salt River Basin (**pl. 4**). The upper part of the Woodside Shale is stratigraphically equivalent to the Red Peak Member of the Chugwater Group or Formation (Kummel, 1954).

Little information is available describing the hydrogeologic characteristics of the Woodside Shale. Robinove and Berry (1963, Plate 1) speculated that the Woodside Shale was likely to yield small quantities of groundwater to wells in the Bear River valley to the south of the Snake/Salt River Basin. The Wyoming Water Planning Program (1972, Table III-2) speculated that the Woodside Shale was a poor aquifer in the Snake/Salt River Basin (**pl. 4**). Lines and Glass (1975, Sheet 1) noted that rocks in the Woodside Shale were relatively impermeable in the Overthrust Belt and in most areas were probably capable of yielding only small quantities of water. Ahern and others (1981, Figure II-7) classified the formation as an aquitard (confining unit and that definition is tentatively retained herein (**pl. 4**).

Chemical characteristics

The chemical characteristics of groundwater from the Woodside confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Woodside confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt
The chemical composition of groundwater in the Woodside confining unit in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs. Individual constituents are listed in **appendix E–5**. Specific conductance measurements (230 and 460 microsiemens per centimeter at 25 degrees Celsius) indicated that both waters were fresh (specific conductance measurements equivalent to TDS concentrations less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the few characteristics and constituents analyzed for in the spring samples, the quality of water from the Woodside confining unit in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming

domestic, agriculture, or livestock water-quality standards.

7.3.37 Dinwoody aquifer and confining unit

The physical and chemical characteristics of the Dinwoody aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Dinwoody aquifer and confining unit is composed of the Lower Triassic Dinwoody Formation (**pls. 4**, **5**, and **6**). The Dinwoody Formation consists of basal, middle, and upper units (Kummel, 1954). In Wyoming, the basal and middle units thin eastward from the Overthrust Belt to zero thickness. The 100- to 300-ft thick upper unit consists of interbedded, tan, calcareous siltstone, gray silty limestone, gray crystalline limestone, and a few shale beds. The 25- to 350-ft thick middle unit of the Dinwoody Formation consists of interbedded, gray silty limestone, gray crystalline limestone, and olive-light tan to gray shale beds. The 50- to 175-ft thick basal unit of the Dinwoody Formation consists of light tan to tan, silty limestone and calcareous siltstone.

Permeability in the Dinwoody aquifer and confining unit likely is small on a regional scale, and thus, in most areas the unit probably is capable of yielding only small quantities of water from permeable zones where fractures and secondary permeability are present (Lines and Glass, 1975, Sheet 1; Ahern and others, 1981, Table IV-1). Ahern and others (1981, Figure II-7, and Table IV-1) classified the Dinwoody Formation as an aquitard (confining unit) with locally productive permeable zones in the Overthrust Belt and the adjacent Green River Basin (**Plates 4** and **5**). The investigators (Ahern and others, 1981, Table IV-1) noted that the most productive parts of the Dinwoody Formation were in areas where fractures were present and in interbedded sandstones in the upper part of the formation. In the Wyoming Water Framework Plan, the Dinwoody Formation was classified as a marginal aquifer (WWDC Engineering and others, 2007, Figure 4-9) (**pls. 4**, **5**, and **6**). Because the unit has low overall permeability, but with distinct zones of higher permeability with potential to yield water to wells, the Dinwoody Formation was classified as both an aquifer and confining unit herein (**pls. 4**, **5**, and **6**). Few hydrogeologic data are available describing the Dinwoody aquifer and confining unit in the Snake/Salt River Basin, but two spring-discharge measurements were inventoried as part of this study and are listed on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Dinwoody aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Dinwoody aquifer and confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–6**).

Northern Ranges
The chemical composition of the Dinwoody aquifer and confining unit in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–2**. The TDS concentration (262 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–2**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Dinwoody aquifer and confining unit in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Star Valley
The chemical composition of the Dinwoody aquifer and confining unit in Star Valley (SV) was characterized and the quality evaluated on the basis of one environmental water sample from

one hot spring. Individual constituents are listed in **appendix E–6**. The TDS concentration (5,250 mg/L) indicated that the water was moderately saline (TDS concentration ranging from 3,000 to 9,999 mg/L) (**appendix E–6**).

Concentrations of some properties and constituents in water from the hot spring issuing from the Dinwoody aquifer and confining unit in SV approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. Concentrations of lead exceeded the USEPA action level of 15 µg/L. Concentrations of one characteristic and two constituents exceeded USEPA aesthetic standards for domestic use: TDS (exceeded SMCL limit of 500 mg/L), chloride (exceeded SMCL limit of 250 mg/L), and sulfate (exceeded SMCL of 250 mg/L). Two characteristics and three constituents approached or exceeded applicable State of Wyoming standards for agricultural use: SAR (exceeded WDEQ Class II standard of 8), TDS (exceeded WDEQ Class II standard of 2,000 mg/L), boron (exceeded WDEQ Class II standard of 750 µg/L), chloride (exceeded WDEQ Class II standard of 100 mg/L), and sulfate (exceeded WDEQ Class II standard of 200 mg/L). One characteristic and one constituent approached or exceeded applicable State of Wyoming livestock water-quality standards: TDS (exceeded WDEQ Class III standard of 2,000 mg/L) and lead (exceeded WDEQ Class III standard of 100 µg/L).

7.4 Paleozoic hydrogeologic units

Paleozoic hydrogeologic units (aquifers and confining units) are described in this section of the report. Lithostratigraphic units of Permian, Pennsylvanian, Mississippian, Devonian, Ordovician, and Cambrian age compose the Paleozoic hydrogeologic units (aquifers and confining units) in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Paleozoic hydrogeologic units underlie Cenozoic and Mesozoic hydrogeologic units in the Snake/Salt River Basin, except in areas where structural deformation has uplifted and exposed the Paleozoic units in the mountains and highlands of the Overthrust Belt. Paleozoic hydrogeologic units are accessible in or very close to these outcrop areas. Depending on location and depth, wells completed in Paleozoic hydrogeologic units produce highly variable quantities and quality of water. The highly complex structural features of the Overthrust Belt require site-specific geologic and hydrogeologic investigation to characterize and develop groundwater resources from Paleozoic hydrogeologic units.

Relatively few water wells are completed in Paleozoic aquifers in the Snake/Salt River Basin, with most along mountain-basin margins where they crop out and are directly exposed at land surface or immediately downgradient in adjacent bordering basins where they occur at shallow depths below younger hydrogeologic units. In these areas, waters are relatively fresh and suitable for most uses. However, permeability decreases and groundwater quality deteriorates rapidly downgradient from outcrop areas along the basin margins. Much of the water used from Paleozoic aquifers in the Snake/Salt River Basin is obtained from springs rather than wells (for example, Star Valley area); many of these springs have moderate to large yields (greater than 100 gal/min).

Paleozoic aquifers produce water from bedrock composed primarily of carbonate rocks [for example, limestone (rock composed of the mineral calcite) and dolostone (rock composed of the mineral dolomite)] and siliciclastic rocks (for example, sandstone) deposited primarily in marine environments. Primary porosity and intergranular permeability are much greater in the sandstones than in the carbonates, where primary permeability is very low. Carbonate aquifers generally may be utilized only in areas where substantial secondary permeability has developed. Permeability of the siliciclastic and carbonate rocks composing the Paleozoic hydrogeologic units may be enhanced by bedding-plane partings, faults, fractures, and solution openings where the rocks have been structurally deformed by folding and faulting in the Overthrust Belt. In fact, development of secondary permeability, such as fractures, faults, and solution openings, in Paleozoic hydrogeologic units usually is required for siting and construction of high yielding springs and wells.

Because data from wells are not available for many Paleozoic hydrogeologic units in the Snake/Salt River Basin, interpretations of the water-bearing properties of some units herein are based on the physical and chemical hydrogeologic characteristics of the same or similar units in other parts of Wyoming. Permeability and groundwater circulation in Paleozoic hydrogeologic units has been studied at many locations in Wyoming, and they are controlled by lithology, sedimentary structure and depositional environment, and tectonic structures such as folds and faults (for example, Lundy, 1978; Huntoon and Lundy, 1979; Thompson, 1979; Eisen and others, 1980; Richter, 1981; Western Water Consultants, Inc., 1982, 1993, 1995; Cooley, 1984, 1986; Davis, 1984; Huntoon, 1985, 1993; Jarvis, 1986; Spencer, 1986; Mills, 1989; Mills and Huntoon, 1989; Wiersma, 1989; Blanchard, 1990; Blanchard and others, 1990; Younus, 1992; Johnson and Huntoon, 1994; Stacy, 1994; Stacy and Huntoon, 1994; Garland, 1996). Except near outcrops, where water-table (unconfined) conditions may be encountered, groundwater in Paleozoic hydrogeologic units is generally semiconfined or confined.

Recharge to Paleozoic hydrogeologic units generally occurs where the units crop out, although severing by faults near recharge areas may disrupt downgradient aquifer continuity and prevent much of this recharge from entering the aquifers downgradient from outcrop areas. Near recharge areas, water in these hydrogeologic units can be relatively fresh and may be suitable for most uses. This is where springs are developed and most wells are completed. Elsewhere, and with increasing depth and as the water moves away from the outcrop, the water can have high TDS, limiting the use of water for most purposes.

7.4.1 Phosphoria aquifer and confining unit

The physical and chemical characteristics of the Phosphoria aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Phosphoria aquifer and confining unit is composed of the Permian Phosphoria Formation (**pls. 4**, **5**, and **6**). The Phosphoria aquifer and confining unit is overlain by the Dinwoody aquifer and confining unit and underlain by the Wells or Tensleep aquifer in most of the Snake/Salt River Basin (**pls. 4**, **5**, and **6**). The Phosphoria Formation consists of an upper part of dark to light gray, cherty shale and sandstone, and a lower part of brown-weathering, dark, phosphatic shale and limestone (Rubey and others, 1980; Love and others, 1992).
The formation is divided into two members at some locations (individual members not shown on Plates 4, 5 and 6). The Rex Chert Member is composed of dark gray siltstone, black, thin-bedded chert and limestone, and a few thin beds of phosphate rock in the upper part. Resistant ledges of gray, cherty, dolomitic limestone and some bedded chert are present in the middle and lower part of the Rex Chert Member (Rubey and others, 1980). The Meade Peak Member consists of dark gray, non-resistant, and brown phosphatic siltstone and cherty siltstone, gray dolomite, several blue beds of phosphorite, and one bed of vanadium-bearing carbonaceous siltstone (Rubey and others, 1980).

Phosphoria Formation thickness varies by geographic area in the Snake/Salt River Basin. Thickness of the Phosphoria Formation decreases eastward in the Overthrust Belt and ranges from about 180 to 361 ft (Love and Love, 1978; Oriel and Platt, 1980; Oriel and Moore, 1985; Rubey and others, 1980; Love and others, 1992; Love and Love, 2000). Thickness of the Phosphoria Formation in the Teton Range ranges from 180 to 220 ft (Love, 1974a,b, 2003a; Christiansen and others, 1978; Oriel and Moore, 1985; Love and Love, 2000). Thickness of the Phosphoria Formation in the Gros Ventre Range ranges from about 180 to about 235 ft (Love and Love, 1978, 2000; Oriel and Platt, 1980; Rubey and others, 1980; Love and others, 1992; Love, 2001b,c; Love and Reed, 2001a).

The Phosphoria Formation is classified as an aquifer, confining unit, or both by previous investigators (**pls. 4**, **5**, and **6**). Robinove and Berry (1963, p. V18) identified the Phosphoria Formation and the underlying Wells Formation as potential Paleozoic aquifers in the Bear River valley to the south of the Snake/Salt River Basin; the investigators noted that both formations "may be expected to yield small to moderate amounts of water to wells." Primary permeability in the Phosphoria aquifer likely is small, and in most areas the unit probably is capable of yielding only "small quantities" of water (Lines and Glass, 1975, Sheet 1). However, in areas where fractures are present and secondary permeability is developed, the aquifer is capable of yielding "moderate quantities" of water (Lines and Glass, 1975, Sheet 1). Ahern and others (1981, Figure II-7, and Table IV-1) classified the Phosphoria Formation as a locally confining minor aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators (Ahern and others, 1981, Table IV-1) noted that the most productive parts of the Phosphoria Formation were in areas where fractures were present and in interbedded sandstones in the upper part of the formation. In the Wyoming Water Framework Plan, the Phosphoria Formation was classified as a minor aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4**, **5**, and **6**). Hydrogeologic data describing the Phosphoria aquifer and confining unit, including spring-discharge and well-yield measurements and other hydraulic properties, are summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Phosphoria aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Phosphoria aquifer and confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–5**).

Northern Ranges

The chemical composition of the Phosphoria aquifer and confining unit in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from three springs. Individual constituents are listed in **appendix E–2**. Major-ion composition in relation to TDS concentrations for springs issuing from the Phosphoria aquifer and confining unit is shown on a trilinear diagram (**appendix F–2, diagram E**). The TDS concentrations for the springs ranged from 95.4 to 164 mg/L, with a median of 119 mg/L, indicating that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram E**). On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Phosphoria aquifer and confining unit in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Phosphoria aquifer and confining unit in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–5**. The specific conductance measured in the spring (320 microsiemens per centimeter at 25 degrees Celsius) indicated that the water was fresh (measured specific conductance equivalent to TDS concentration less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for in the spring sample, the quality of water from the Phosphoria aquifer and confining unit in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.2 Quadrant Sandstone

Within the Snake/Salt River Basin, the Pennsylvanian Quadrant Sandstone (also known as the Quadrant Quartzite) is present only in the Yellowstone Volcanic Area (**pl. 1; pl. 6**), and consists of well-bedded white to pink, fine-to medium-grained quartzite (Mallory, 1967). The Quadrant Sandstone is laterally equivalent to the Tensleep Sandstone. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic unit in the Snake/Salt River Basin.

7.4.3 Tensleep aquifer

The physical and chemical characteristics of the Tensleep aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Tensleep aquifer is composed of saturated and permeable parts of the Middle to Upper Pennsylvanian to Permian Tensleep Sandstone (**pls. 5** and **6**). The Tensleep Sandstone consists of light-gray, weathering yellowish brown, fine-grained hard brittle sandstone; some zones are quartzitic (Love and others, 1992). The middle and lower parts of the formation contain many beds of gray, hard fine-grained limestone and dolomite. The Tensleep Sandstone is transitional with the underlying Amsden Formation. The Tensleep Sandstone is stratigraphically equivalent to the Wells Formation—the lithostratigraphic unit is identified as the Wells Formation south and west of the Jackson thrust fault and as the Tensleep Sandstone north and east of the Jackson thrust fault (Love and others, 1992). Thickness of the Tensleep Sandstone ranges from about 385 to about 450 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972, 1987; Jobin, 1972; Love, 1974a,b, 1975b, 2001a,b,c, 2003a; Christiansen and others, 1978; Love and Love, 1978; Oriel and Moore, 1985; Love and others, 1992).

The Tensleep aquifer is overlain by the Phosphoria aquifer and confining unit and underlain by the Amsden aquifer (**pls. 5** and **6**). In the eastern Gros Ventre Range, the Tensleep aquifer is confined from above by the Phosphoria-Dinwoody-Chugwater confining unit (composed of most of the Phosphoria Formation and the Dinwoody and Chugwater Formations) and from below by the Amsden confining unit composed of the Amsden Formation (Mills, 1989; Mills and Huntoon, 1989) (**pl. 5**). In addition, the Tensleep aquifer in the eastern Gros Ventre Range also is composed of hydraulically connected lower sandstones in the overlying Phosphoria Formation (Mills, 1989; Mills and Huntoon, 1989) (**pl. 5**).

The Tensleep Sandstone is classified as an aquifer by all investigators and that definition is retained herein (**pls. 5** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Tensleep Sandstone was a poor to good aquifer in the Snake/Salt River Basin (**pls. 5** and **6**). Ahern and others (1981, Figure II-7, and Table IV-1) classified the Tensleep Sandstone and the equivalent Wells Formation as major aquifers in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators also considered the Wells/Tensleep aquifer to be part of a larger regional Paleozoic aquifer system composed of many different hydrogeologic units (**pls. 4** and **5**). Mills (1989) and Mills and Huntoon (1989) classified the formation as an aquifer in the eastern Gros Ventre Range (**pl. 5**). In the Wyoming Water Framework Plan, the Wells Formation was classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**).

Lines and Glass (1975, Sheet 1) noted that sandstone beds composing the Tensleep Sandstone were aquifers capable of yielding moderate to large quantities of water (100 gal/min or more), depending upon local recharge, sandstone bed continuity, and development of secondary permeability from fractures. In addition, the investigators (Lines and Glass, 1975, Sheet 1) noted that sandstone beds "on topographic highs may be drained [unsaturated], especially if underlying limestones have extensive solution development." Several investigators (Cox, 1976; Mills, 1989; Mills and Huntoon, 1989) reported yields as much as 100 gal/min or more to individual springs in the Gros Ventre Range. Mills (1989) and Mills and Huntoon (1989) noted that permeability in lithologic units composing the aquifer in the eastern Gros Ventre Range was both primary and secondary. Permeability in sandstones in the Tensleep aquifer was determined to be intergranular along the backlimbs of examined folds, but could be secondarily enhanced due to fractures and associated piping along the forelimbs of examined folds (Mills, 1989; Mills and Huntoon, 1989). Primary permeability of dolomite in the Tensleep aquifer was small along the forelimbs of examined folds, but was enhanced due to fracturing and karstification along the forelimbs of examined folds.

Hydrogeologic information describing the Tensleep aquifer, including well-yield and spring-discharge measurements and other hydraulic properties, is summarized on **plate 3**. Spring-discharge measurements and well yields inventoried as part of this study (**pl. 3**) confirm that sandstone aquifers in the Tensleep Sandstone are capable of yielding moderate to large quantities of water (100 gal/min or more) in parts of the Snake/Salt River Basin.

Chemical characteristics

The chemical characteristics of groundwater from the Tensleep aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Tensleep aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–4**).

Northern Ranges
The chemical composition of the Tensleep aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water sample from as many as six springs. Summary statistics calculated for available constituents are listed in **appendix E–2**. Major-ion composition in relation to TDS concentrations for springs issuing from the Tensleep aquifer is shown on a trilinear diagram (**appendix F–2, diagram F**). TDS concentrations indicated that the water was fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram F**). The TDS concentrations for the springs ranged from 123 to 312 mg/L, with a median of 268 mg/L. On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Tensleep aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole
The chemical composition of the Tensleep aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one produced water sample from one well. The TDS concentration (1,980 mg/L) indicated that the water was slightly saline (TDS concentration ranging from 1,000 to 2,999 mg/L). The pH value in the produced water sample was 7.2. Measured concentrations of cations were 468 mg/L (sodium), 190 mg/L (calcium), and 27 mg/L (magnesium). Measured concentrations of anions were 854 mg/L (sulfate), 684 mg/L (bicarbonate), and 110 mg/L (chloride).

Concentrations of some properties and constituents in water from the Tensleep aquifer in the JH produced water sample approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: TDS (exceeded SMCL limit of 500 mg/L) and sulfate (exceeded SMCL of 250 mg/L). Two constituents in the produced water sample approached or exceeded applicable State of Wyoming standards for agricultural-use standards: chloride (exceeded WDEQ Class II standard of 100 mg/L) and sulfate (exceeded WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

Green River and Hoback Basins
The chemical composition of the Tensleep aquifer in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituent concentrations are

listed in **appendix E–4**. The TDS concentration (303 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–4**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Tensleep aquifer in the GH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.4 Wells aquifer

The physical and chemical characteristics of the Wells aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Wells aquifer is composed of the Middle to Upper Pennsylvanian to Permian Wells Formation (**pl. 4**). The Wells Formation consists of interbedded gray limestone and pale yellow calcareous sandstone with minor gray dolomite beds; the lower part of the formation is cherty (Love and others, 1992). The Wells Formation is stratigraphically equivalent to the Tensleep Sandstone—the lithostratigraphic unit is identified as the Wells Formation south and west of the Jackson thrust fault and as the Tensleep Sandstone north and east of the Jackson thrust fault (Love and others, 1992). Thickness of the Wells Formation in the Overthrust Belt ranges from about 591 to about 1,969 ft (Jobin, 1965, 1972; Pampeyan and others, 1967; Albee, 1968, 1973; Schroeder, 1973, 1974, 1976, 1979, 1981, 1987; Love and Love, 1978; Oriel and Platt, 1980; Oriel and Moore, 1985; Schroeder and others, 1981; Love and others, 1992).

The Wells Formation is classified as an aquifer by most investigators and that definition is retained herein (**pl. 4**). Berry (1955) identified the Wells Formation (referred to as the Tensleep Sandstone) as a potential aquifer (**pl. 4**) in the Cokeville area to the south of the Snake/Salt River Basin in the Overthrust Belt. Robinove and Berry (1963, p. V18) identified the Wells Formation and overlying Phosphoria Formation as potential Paleozoic aquifers in the Bear River valley to the south of the Snake/Salt River Basin in the Overthrust Belt; the investigators noted that both formations "may be expected to yield small to moderate amounts of water to wells." Similarly, Lines and Glass (1975, Sheet 1) noted that sandstone beds composing the formation were aquifers capable of yielding moderate to large quantities of water, depending upon local recharge, sandstone bed continuity, and development of secondary permeability from fractures. In addition, the investigators (Lines and Glass, 1975, Sheet 1) noted that sandstone beds "on topographic highs may be drained, especially if underlying limestones have extensive solution development." Cox (1976, Sheet 1) speculated that sandstones in the formation might yield a few tens of gallons per minute per well. Ahern and others (1981, Figure II-7, and Table IV-1) classified the Wells Formation and the equivalent Tensleep Sandstone as major aquifers in the Overthrust Belt and adjacent Green River Basin (**pl. 4**). In the Wyoming Water Framework Plan, the Wells Formation was classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pl. 4**). Hydrogeologic information describing the Wells aquifer, including well-yield and spring-discharge measurements and other hydraulic characteristics, is summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Wells aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Wells aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–5**).

Overthrust Belt

The chemical composition of groundwater in the Wells aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as 12 springs and 1 well. Summary statistics calculated for available constituents are listed in

appendix E–5. Major ion composition in relation to TDS for springs issuing from the Wells aquifer is shown on a trilinear diagram (**appendix F–5, diagram I**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram I**). The TDS concentrations for the springs ranged from 114 to 239 mg/L, with a median of 171 mg/L. The TDS concentration for the well was 317 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Wells aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.5 Amsden aquifer

The physical and chemical characteristics of the Amsden aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Amsden aquifer is composed of saturated and permeable parts of the Upper Mississippian to Pennsylvanian Amsden Formation (**pls. 4, 5,** and **6**). The Amsden Formation consists of red and gray cherty limestone and yellow siltstone, sandstone, and conglomerate (Mallory, 1967; Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980; Love and others, 1992; and M'Gonigle and Dover, 1992). The Amsden Formation overlies the Madison Group or Limestone north and east of the Jackson thrust fault and is overlain by the stratigraphically equivalent Wells Formation south and west of the Jackson thrust fault. The Amsden Formation has as many as three members in the Snake/Salt River Basin: Ranchester Limestone Member (Pennsylvanian); Horseshoe Shale Member (Upper Mississippian to Lower Pennsylvanian); and Darwin Sandstone Limestone Member (Upper Mississippian) (Mallory, 1967).

Thickness of the Amsden Formation varies by geographic area in the Snake/Salt River Basin. Thickness of the Amsden Formation in the Gros Ventre Range is about 400 to 450 ft (Love and Reed, 2000, 2001a,b; Love, 2001a,c, 2003c; Love and others, 1992). Thickness of the Amsden Formation in the Teton Range ranges from 230 to 700 ft (Schroeder, 1972; Love, 1974a,b, 2003a; Christiansen and others, 1978; Oriel and Moore, 1985). Thickness of the Amsden Formation in the Overthrust Belt ranges from about 328 to about 700 ft (Oriel and Platt, 1980; Love and others, 1992).

The Amsden Formation in the Snake/Salt River Basin is classified as either an aquifer or confining unit by previous investigators, depending upon the physical characteristics of the unit in the area examined (**pls. 4, 5,** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Amsden Formation was a fair to poor aquifer in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Lines and Glass (1975, Sheet 1) noted that small quantities of water might be available from cherty limestone in the formation in the Overthrust Belt, but "on topographic highs, the Amsden Formation is probably well-drained, especially if underlying limestones have extensive solution development." Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a minor locally confining aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators also considered the Amsden aquifer to be part of a larger regional Paleozoic aquifer system composed of many different hydrogeologic units (**pls. 4** and **5**). In the eastern Gros Ventre Range and the Salt River Range, general permeability of the shale and limestone composing much of the Amsden Formation is small enough that the lithostratigraphic unit is considered a confining unit that overlies the Madison aquifer, and underlies the Tensleep aquifer (Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990) (**pls. 4** and **5**). However, the investigators noted that sandstones in the Amsden Formation were permeable and that sandstone permeability was intergranular. In the Wyoming Water Framework Plan, the Amsden Formation was classified as a marginal aquifer throughout Wyoming (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Amsden Formation in the adjacent Green

River Basin and surrounding areas have classified the formation as an aquifer (Ahern and others, 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein). In the upper Colorado River Basin and adjacent areas (including Green River Basin and parts of the Overthrust Belt), Geldon (2003) classified the Ranchester Limestone and the Darwin Sandstone Members as aquifers and the Horseshoe Shale Member as a confining unit (see Bartos and Hallberg, 2010, Figure 5-4). Hydrogeologic information describing the Amsden aquifer, including well-yield and spring-discharge measurements and other hydraulic properties, is summarized on **plate 3**.

Chemical characteristics

The chemical characteristics of groundwater from the Amsden aquifer in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Amsden aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2, E–3,** and **E–5**).

Northern Ranges
The chemical composition of the Amsden aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–2**. The TDS concentration (56.3 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–2**). On the basis of the characteristics and constituents analyzed for in the one spring sample, the quality of water from the Amsden aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole
The chemical composition of the Amsden aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituents are listed in **appendix E–3**. The TDS concentration (327 mg/L) indicated that the water was fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for in the one sample, the quality of water from the Amsden aquifer in JH was suitable for most uses, although the concentration of one constituent exceeded health-based standards: radon (the 1 sample analyzed for this constituent exceeded the proposed USEPA MCL of 300 pCi/L, but did not exceed the AMCL of 4,000 pCi/L). No characteristics or constituents approached or exceeded applicable State of Wyoming agriculture or livestock water-quality standards.

Overthrust Belt
The chemical composition of groundwater in the Amsden aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from three springs. Individual constituents are listed in **appendix E–5**. Major ion composition in relation to TDS for springs issuing from the Amsden aquifer is shown on a trilinear diagram (**appendix F–5, diagram J**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram J**). The TDS concentrations for the springs ranged from 119 to 178 mg/L, with a median of 138 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Amsden aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.6 Madison aquifer

The physical and chemical characteristics of the Madison aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Lower to Upper Mississippian Madison Limestone is a thick sequence of carbonate rocks [limestone (carbonate rock composed of the mineral calcite) and dolostone (carbonate rock composed of the mineral dolomite)] that consists of two parts—an upper part of light- to dark-gray, thick-bedded to massive limestone, and a lower part of dark gray, thin-bedded limestone and dolomite (Lines and Glass, 1975; Oriel and Platt, 1980; Love and others, 1992). In the vicinity of Grand Teton National Park, thin lenses of brown cherty dolomite are present near the base and lenses of black chert are common (Love and others, 1992). Thickness of the Madison Limestone in the Gros Ventre and Teton Ranges ranges from about 1,100 to 1,500 ft (Love and Love, 1978; Oriel and Platt, 1980; Love and others, 1992). Thickness of the Madison Group or Limestone in the Overthrust Belt ranges from about 800 to about 1,800 ft (Oriel and Platt, 1980; Schroeder, 1974, 1976, 1979, 1981, 1987; Schroeder and others, 1981; Lageson, 1986).

Saturated and permeable parts of the Madison Group or Limestone compose the Madison aquifer. The Madison Group or Limestone in the Snake/Salt River Basin is classified as an aquifer by all previous investigators (**pls. 4, 5,** and **6**). The Madison aquifer is overlain by the Amsden aquifer and underlain by the Darby aquifer (**pls. 4, 5,** and **6**). In the eastern Gros Ventre Range and the Salt River Range, the Madison aquifer is part of different aquifer systems composed of other Paleozoic aquifers with varying degrees of hydraulic connection (Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990) (**pls. 4** and **5**).

Primary permeability (intergranular or intercrystalline) of the Madison Group or Limestone generally is low, and large volumes of the formation are composed of relatively impermeable rocks (for example, Mills, 1989; Mills and Huntoon, 1989). The availability of water from the Madison aquifer depends substantially on the development of secondary permeability, primarily fractures and karstic features such as solution openings. Where permeability has been enhanced by fracturing and solution openings, the Madison Group or Limestone is one of the most productive aquifers in the Snake/Salt River Basin (**pl. 3**), as well as in many other areas of Wyoming (for example, Bartos and others, 2012, and references therein).

In areas where secondary permeability is developed, springs issuing from and wells completed in the Madison aquifer may yield several hundred gallons per minute (Lines and Glass, 1975; Cox, 1976; Huntoon and Coogan, 1987; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990; Sunrise Engineering, 2003, 2009) (**pl. 3**). Some of these springs issuing from the Madison aquifer are used to provide water for public-supply purposes in the Snake/Salt River Basin [notably, Periodic Spring is used to provide a substantial amount of the water supply for the city of Afton (Huntoon and Coogan, 1987, and references therein; Forsgren Associates, 1990; Sunrise Engineering, 2009)]. Fracturing of rocks composing the Madison Group or Limestone (and other Paleozoic hydrogeologic units) generally occurs in areas of structural deformation such as near faults and on the limbs of folds (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990; Rendezvous Engineering, PC, and Hinckley Consulting, 2009). Solution openings generally develop in outcrop areas or near land surface where recharging waters containing carbon dioxide dissolve parts of the aquifer until eventually discharging from the aquifer (Lines and Glass, 1975; Cox, 1976; Huntoon and Coogan, 1987; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990). Fracturing and faulting provides a pathway for vertical movement of groundwater between different Paleozoic aquifers (including the Madison aquifer) at some locations in the Snake/Salt River Basin (Mills, 1989; Mills and Huntoon, 1989).

In the Snake/Salt River Basin, much of the water discharged from the Madison aquifer and other Paleozoic aquifers is through a few large springs where there has been selective enlargement of solution openings and a concentration of flow in a few of the larger openings (Lines and Glass, 1975; Cox, 1976; Huntoon and Coogan, 1987; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990). Outcrops on topographic highs commonly are unsaturated (drained) to depths of several hundred feet. Lines and Glass (1976, Sheet 1) noted that wells that penetrated "water-bearing solution channels" were likely to "yield much more water than wells that do not penetrate the major conduits." Unlike limestones in other Paleozoic hydrogeologic units of the Snake/Salt River Basin, outcrops of the Madison Group or Limestone have ancient karstic features such as solution openings that probably developed before and during deposition of the overlying Amsden Formation (Lines and Glass, 1975; Mills, 1989; Mills and Huntoon, 1989). Consequently, solution permeability in the Madison aquifer probably is present at greater depths below the present land surface than in other Paleozoic hydrogeologic units.

Recharge to the Madison aquifer is from direct infiltration of precipitation (snowmelt and rain), snowmelt runoff, lakes, and ephemeral and perennial streamflow losses on outcrops (Lines and Glass, 1975; Cox, 1976; Huntoon and Coogan, 1987; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990). This recharge may be enhanced in areas where fractures occur along the axes of anticlines or in karstified areas (Huntoon and Coogan, 1987; Mills, 1989; Mills and Huntoon, 1989; Blanchard, 1990; Blanchard and others, 1990). Discharge from the Madison aquifer occurs from withdrawals by pumped wells and naturally by evapotranspiration, gaining streams, seeps, and spring flows. Hydrogeologic data describing the Madison aquifer, including well-yield and spring-discharge measurements and other hydraulic properties, is summarized on **plate 3**.

Chemical characteristics

The chemical composition of groundwater in the Madison aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Madison aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–1** to **E–6**).

Yellowstone Volcanic Area

The chemical composition of the Madison aquifer in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of environmental water samples from one spring and two wells. Individual constituents are listed in **appendix E–1**. TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–1**). The TDS concentration in the spring was 245 mg/L. The TDS concentrations for the wells were 128 and 138 mg/L. On the basis of the characteristics and constituents analyzed for in the spring and well samples, the quality of water from the Madison aquifer in the YVA was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of Madison aquifer in the YVA also was characterized and the quality evaluated on the basis of environmental water samples from as many as three hot springs. Individual constituents are listed in **appendix E–1**. Major ion composition in relation to TDS for the three hot springs issuing from the Madison aquifer in the YVA is shown on a trilinear diagram (**appendix F–1, diagram G**). TDS concentrations indicated that waters ranged from slightly saline (2 of 3 samples, TDS concentrations between 1,000 to 2,999 mg/L) to fresh (1 of 3 samples, TDS concentration less than or equal to 999 mg/L) (**appendix E–1; appendix F–1, diagram G**). TDS concentrations for the hot springs ranged from 695 to 1,960 mg/L, with a median of 1,550 mg/L.

Concentrations of some properties and constituents in water from the three hot springs issuing from the Madison aquifer in the YVA approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Concentrations of two constituents exceeded health-based standards: boron (all 3 samples exceeded the WDEQ Class II standard of 750 μg/L) and fluoride (1 of 3 samples exceeded the USEPA MCL of 4 mg/L). Concentrations of one characteristic and two constituents exceeded USEPA aesthetic standards for domestic use: TDS (all 3 samples exceeded the SMCL of 500 mg/L), fluoride (all 3 samples exceeded the SMCL of 2 mg/L), and sulfate (2 of 3 samples exceeded the SMCL of 250 mg/L).

Concentrations of some characteristics and constituents in water from the three hot springs issuing from the Madison aquifer in the YVA exceeded State of Wyoming standards for agricultural and livestock use. Three constituents were measured at concentrations greater than agricultural-use standards: boron (all 3 samples exceeded the WDEQ Class II standard of 750 μg/L), chloride (all 3 samples exceeded the WDEQ Class II standard of 100 mg/L), and sulfate (2 of 3 samples exceeded the WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

Northern Ranges

The chemical composition of the Madison aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as five springs and one cave. Summary statistics calculated for available constituents in the five springs and one cave sample are listed in **appendix E–2** (one cave sample grouped with five spring samples for summary purposes in **appendix E–2**). Major ion composition in relation to TDS for the springs issuing from the Madison aquifer in the NR is shown on a trilinear diagram (**appendix F–2, diagram G**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram G**). The TDS concentrations for the springs and cave ranged from 31.5 to 106 mg/L, with a median of 89.0 mg/L. The TDS concentration in water issuing from the cave was less than 83 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Madison aquifer in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole

The chemical composition of the Madison aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of environmental water samples from as many as six springs and one well. Summary statistics calculated for available constituents are listed in **appendix E–3**. Major ion composition in relation to TDS for the springs issuing from the Madison aquifer in JH is shown on a trilinear diagram (**appendix F–3, diagram I**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–3; Appendix F–3, diagram I**). The TDS concentrations for the springs ranged from 127 to 588 mg/L, with a median of 273 mg/L. The TDS concentration in the well was 262 mg/L.

Concentrations of some properties and constituents in water from the Madison aquifer in JH approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Concentrations of one characteristic and one constituent in one of the six spring samples exceeded USEPA aesthetic standards for domestic use: TDS (exceeded SMCL limit of 500 mg/L) and sulfate (exceeded SMCL of 250 mg/L). One constituent in one of the six spring samples approached or exceeded applicable State of Wyoming standards for agricultural-use standards: sulfate (exceeded WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

On the basis of the characteristics and constituents analyzed for, the quality of water from the Madison aquifer in wells and springs in JH was suitable for most uses, as no concentrations of constituents exceeded health-based standards. No characteristics or constituents in the well sample approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Green River and Hoback Basins

The chemical composition of the Madison aquifer in the Green River and Hoback Basins (GH) was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituent concentrations are listed in **appendix E–4**. The TDS concentrations (94.6 and 102 mg/L) indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–4**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Madison aquifer in the GH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Madison aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as 18 springs, 2 wells, and 1 hot spring. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major ion composition in relation to TDS for the 18 springs issuing from the Madison aquifer in the OTB is shown on a trilinear diagram (**appendix F–5, diagram K**). TDS concentrations indicated that waters in all 18 springs (**appendix F–5, diagram K)** and one of two wells were fresh (TDS concentrations less than or equal to 999 mg/L), and waters from the hot spring and one of two wells were slightly saline (TDS concentrations ranging from 1,000 to 2,999 mg/L) (**appendix E–5**). The TDS concentrations for the 18 springs ranged from 89.0 to 319 mg/L, with a median of 194 mg/L. The TDS concentrations for the wells were 110 and 1,150 mg/L. The TDS concentration in the hot spring was 1,160 mg/L.

On the basis of the characteristics and constituents analyzed for in the 18 spring samples, the quality of water from the Madison aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Concentrations of some properties and constituents in water from the two wells and the hot spring in the Madison aquifer in the OTB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use in one of the two well samples and in the hot spring sample: TDS (exceeded the SMCL of 500 mg/L) and sulfate (exceeded the SMCL of 250 mg/L). One constituent approached or exceeded applicable State of Wyoming standards for agricultural-use standards in one of the two well samples and in the hot spring sample: sulfate (exceeded the WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards in samples from the two wells or the hot spring.

The chemical composition of the Madison aquifer in the OTB also was characterized and the quality evaluated on the basis of one produced water sample from one well. The TDS concentration (5,600 mg/L) indicated that the water was moderately saline (TDS concentration ranging from 3,000 to 9,999 mg/L). The pH value in the produced water sample was 8.5. Measured concentrations of cations were 1,780 mg/L (sodium), 151 mg/L (calcium), 54 mg/L (magnesium), and 25 mg/L (potassium). Measured concentrations of anions were 2,200 mg/L (sulfate), 1,870 mg/L (bicarbonate), and 440 mg/L (chloride).

Concentrations of some properties and constituents in the produced water sample from the Madison aquifer in the OTB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for most uses. Concentrations of one characteristic and two constituents exceeded USEPA aesthetic standards for domestic use and State of Wyoming standards for agricultural use: TDS (exceeded SMCL limit of 500 mg/L and WDEQ Class II standard of 2,000 mg/L), chloride (exceeded SMCL of 250 mg/L and WDEQ Class II standard of 100 mg/L), and sulfate (exceeded SMCL of 250 mg/L and WDEQ Class II standard of 200 mg/L). One characteristic approached or exceeded applicable State of Wyoming livestock water-quality standards: TDS (exceeded WDEQ Class III standard of 5,000 mg/L).

Star Valley
The chemical composition of the Madison aquifer in Star Valley (SV) was characterized and the quality evaluated on the basis of environmental water samples from as many as six wells. Summary statistics calculated for available constituents are listed in **appendix E–6**. Major ion composition in relation to TDS for the wells in the Madison aquifer in the SV is shown on a trilinear diagram (**appendix F–6, diagram C**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–6**). TDS concentrations for the wells ranged from 244 to 349 mg/L, with a median of 311 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Madison aquifer in SV was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

The chemical composition of a Paleozoic limestone (may be Madison aquifer) underlying the Salt Lake Formation in Star Valley (SV) was characterized and the quality evaluated on the basis of environmental water samples from as many as two wells. Individual constituents are listed in **appendix E–6**. The TDS concentration (169 mg/L) from one well indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–6**). On the basis of the characteristics and constituents analyzed for, the quality of water from a Paleozoic limestone aquifer in SV was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.7 Three Forks and Jefferson Formations

Within the Snake/Salt River Basin, the Upper Devonian Three Forks Formation is present only in the Yellowstone Volcanic area (**pl. 1; pl. 6**) and consists of pink, yellow, and green, dolomitic siltstone and shale (Love and Christiansen, 1985, Sheet 2). Within the Snake/Salt River Basin, the Upper Devonian Jefferson Formation also is present only in the Yellowstone Volcanic Area (**pl. 1; pl. 6**) and consists of massive siliceous dolomite and limestone (Love and Christiansen, 1985, Sheet 2). Cox (1976, Sheet 1) speculated that wells completed in either formation probably would not yield more than a few gallons per minute. No data were located describing the physical and chemical hydrogeologic characteristics of either lithostratigraphic unit in the Snake/Salt River Basin.

7.4.8 Darby aquifer

The physical and chemical characteristics of the Darby aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Darby aquifer is composed of saturated and permeable parts of the Upper Devonian to Lower Mississippian Darby Formation (**pls. 4, 5,** and **6**). The Darby Formation consists of an upper part of dull-yellow, gray, pink, and black thin-bedded dolomitic siltstone and shale, and a lower part of brown, vuggy, siliceous, brittle dolomite containing sparse thin limestone beds and thin sandstone beds (Love and others, 1992).

Thickness of the Darby Formation varies by geographic area in the Snake/Salt River Basin. Thickness of the Darby Formation in the Gros Ventre Range ranges from about 285 to 450 ft (Love and others, 1992). Thickness of the Darby Formation in Jackson Hole is about 250 ft (Love, 2003b). Thickness of the Darby Formation in the Teton Range ranges from about 250 to 450 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972; Christiansen and others, 1978; Love and others, 1992). Thickness of the Darby Formation in the Overthrust Belt ranges from about 285 to 700 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972, 1973, 1974, 1976, 1981, 1987; Jobin, 1972; Albee, 1973; Albee and Cullins, 1975; Oriel and Platt, 1980; Schroeder and others, 1981; Lageson, 1986; Love and others, 1992; Love and Love, 2000; Love, 2003c).

The Darby Formation in the Snake/Salt River Basin is classified as an aquifer by previous investigators (**pls. 4, 5,** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Darby Formation was a fair to poor aquifer in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Lines and Glass (1976, Sheet 1) speculated that the Darby Formation probably would not yield more than a few gallons per minute per well. Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators also considered the Darby aquifer to be part of a larger regional Paleozoic aquifer system composed of many different Paleozoic hydrogeologic units (**pls. 4** and **5**). In the eastern Gros Ventre Range and the Salt River Range, the Darby Formation is classified as an aquifer and is considered part of an aquifer system composed of other Paleozoic hydrogeologic units with varying amounts of hydraulic connection (**pls. 4** and **5**). In the Wyoming Water Framework Plan, the Darby Formation was classified as a major aquifer throughout Wyoming (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Darby Formation in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer or confining unit (Ahern and others, 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein). In the upper Colorado River Basin and adjacent areas (including Green River Basin, and parts of the Overthrust Belt), Geldon (2003) classified the Darby Formation as a regional confining unit (see Bartos and Hallberg, 2010, Figure 5-4). In the Wind River and Bighorn Basins east of the Snake/Salt River Basin, the Darby Formation was classified as an aquifer (**pl. 6**) (Bartos and others, 2012, and references therein). Permeability of the dolomite that comprises much of the Darby Formation in the eastern Gros Ventre Range primarily is intercrystalline (Mills, 1989; Mills and Huntoon, 1989). Spring-discharge measurements for the Darby aquifer in the Snake/Salt River Basin are summarized on **plate 3**.

Chemical characteristics

The chemical composition of groundwater in the Darby aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Darby aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–1** and **E–5**).

Yellowstone Volcanic Area

The chemical composition of the Darby aquifer in the Yellowstone Volcanic Area (YVA) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituents are listed in **appendix E–1**. The TDS concentration (183 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–1**). On the basis of the characteristics and constituents analyzed for, the quality of water from the Darby aquifer in the YVA was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt

The chemical composition of groundwater in the Darby aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as four springs. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major ion composition in relation to TDS for springs issuing from the Darby aquifer in the OTB is shown on a trilinear diagram (**appendix F–5, diagram L**). TDS concentrations indicated that waters from two of the four springs were fresh (TDS concentrations less than or equal to 999 mg/L), and waters from the other two springs were slightly saline (TDS concentrations ranging from 1,000 to 2,999 mg/L) (**appendix E–5; appendix F–5, diagram L**). The TDS concentrations for the springs ranged from 134 to 1,330 mg/L, with a median of 719 mg/L.

Concentrations of some properties and constituents in water from springs issuing from the Darby aquifer in the OTB approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. Most environmental waters were suitable for domestic use, as no concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use in two of the four spring samples: TDS (exceeded the SMCL of 500 mg/L) and sulfate (exceeded the SMCL of 250 mg/L). One constituent (sulfate) approached or exceeded the applicable State of Wyoming standard for agricultural use (two of the four springs exceeded the WDEQ Class II standard of 200 mg/L). No characteristics or constituents measured in springs issuing from the Darby aquifer approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.4.9 Bighorn aquifer

The physical and chemical characteristics of the Bighorn aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Bighorn aquifer is composed of saturated and permeable parts of the Upper Ordovician Bighorn Dolomite (**pls. 4, 5,** and **6**). The Bighorn Dolomite consists of gray massive dolomite and dolomitic limestone (Love and others, 1992). Thickness of the Bighorn Dolomite varies by geographic area in the Snake/Salt River Basin. Thickness of the Bighorn Dolomite in the Gros Ventre Range ranges from about 200 to 500 ft (Love and others, 1992). Thickness of the Bighorn Dolomite in the Teton Range ranges from about 400 to 440 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972; Christiansen and others, 1978; Oriel and Moore, 1985; Love and others, 1992). Thickness of the Bighorn Dolomite in the Overthrust Belt ranges from about 400 to 820 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972, 1973, 1976, 1979; Jobin, 1972; Albee and Cullins, 1975; Oriel and Platt, 1980; Oriel and Moore, 1985; Lageson, 1986; Love and others, 1992; Love and Love, 2000; Love, 2003c).

The Bighorn Dolomite is classified as an aquifer by previous investigators (**pls. 4, 5,** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Bighorn Dolomite was a fair to poor aquifer in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a major aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators also considered the Bighorn aquifer to be part of a larger regional Paleozoic aquifer system composed of many different Paleozoic hydrogeologic units (**pls. 4** and **5**). In the eastern Gros Ventre Range and the Salt River Range, the Bighorn Dolomite is classified as an aquifer and is considered part of an aquifer system composed of other Paleozoic hydrogeologic units with varying amounts of hydraulic connection (**pls. 4** and **5**). In the Wyoming Water Framework Plan, the Bighorn Dolomite was classified as a major aquifer throughout Wyoming (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Bighorn Dolomite in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer or confining unit (Ahern and others, 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein). In the upper Colorado River Basin and adjacent areas (including Green River Basin, and parts of the Overthrust Belt), Geldon (2003) classified the Bighorn Dolomite as a regional confining unit (see Bartos and Hallberg, 2010, Figure 5-4). In the Wind River and Bighorn Basins east of the Snake/Salt River Basin, the Bighorn Dolomite was classified as an aquifer (**pl. 6**) (Bartos and others, 2012, and references therein).

Permeability of the dolomite that composes much of the Bighorn aquifer is both primary (intercrystalline) and secondary (fractures and solution openings) (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Large spring discharges (100 gal/min or more) inventoried as part of this study (**pl. 3**) primarily are attributable to fractures and solution openings (Lines and Glass, 1975; Cox, 1976; Mills, 1989;

Mills and Huntoon, 1989). Spring-discharge measurements inventoried in the Bighorn aquifer in the Snake/Salt River Basin are summarized on **plate 3**.

Chemical characteristics

The chemical composition of groundwater in the Bighorn aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Bighorn aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–5**).

Northern Ranges
The chemical composition of the Bighorn aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as three springs and one well. Individual constituents are listed in **appendix E–2**. Major ion composition in relation to TDS for springs issuing from the Bighorn aquifer in the NR is shown on a trilinear diagram (**appendix F–2, diagram H**). TDS concentrations indicated that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram H**). The TDS concentrations for the springs ranged from 37.1 to 107 mg/L, with a median of 96.0 mg/L. The TDS concentration for the well was 270 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Bighorn aquifer in the NR was suitable for most uses. No characteristics or constituents in the spring or well samples approached or exceeded applicable USEPA standards or State of Wyoming domestic or livestock water-quality standards. One characteristic in the well sample approached or exceeded applicable State of Wyoming standards for agricultural-use standards: SAR (exceeded WDEQ Class II standard of 8).

Overthrust Belt
The chemical composition of groundwater in the Bighorn aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from as many as eight springs. Summary statistics calculated for available constituents are listed in **appendix E–5**. Major ion composition in relation to TDS for springs issuing from the Bighorn aquifer in the OTB is shown on a trilinear diagram (**appendix F–5, diagram M**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5; appendix F–5, diagram M**). The TDS concentrations for the springs ranged from 104 to 188 mg/L, with a median of 160 mg/L. On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Bighorn aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.10 Gallatin aquifer

The physical and chemical characteristics of the Gallatin aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Gallatin aquifer is composed of saturated and permeable parts of the Upper Cambrian Gallatin Group or Limestone (**pls. 4, 5,** and **6**). The Gallatin Group or Limestone consists of interbedded, gray, mottled yellow and tan, thin-bedded to massive limestone and dolostone (dolomite); some green shale is present in the middle of the formation and some conglomerate is present in the lower part of the formation (Lines and Glass 1975; Oriel and Platt, 1980; Rubey and others, 1980; Love and others, 1992). In the Yellowstone Volcanic Area and Teton and Gros Ventre Ranges, the "Gallatin" is elevated to group rank and is composed of an upper formation, the Snowy Range Formation, and a lower formation, the Pilgrim Limestone (**pls. 5** and **6**).

Thickness of the Gallatin Limestone varies by geographic area in the Snake/Salt River Basin. Thickness of the Gallatin Group or Limestone in the Gros Ventre Range ranges from about 180 to 250 ft (Love and Love, 1978; Love and others, 1992; Love and Love, 2000; Love, 2001a,b; Love and Reed, 2001a). Thickness of the Gallatin Group or Limestone in the Teton Range ranges from about 125 to 250 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972; Oriel and Moore, 1985; Love and others, 1992; Love and Reed, 2000, 2001b; Love, 2003a). Thickness of the Gallatin Group or Limestone in the Overthrust Belt ranges from about 120 to 250 ft (Pampeyan and others, 1967; Schroeder, 1969, 1972; Jobin, 1972; Albee and Cullins, 1975; Oriel and Platt, 1980; Oriel and Moore, 1985; Lageson, 1986; Love and others, 1992).

The Gallatin Group or Limestone is classified as an aquifer or confining unit by previous investigators (**pls. 4, 5,** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Gallatin Group or Limestone was probably a poor aquifer in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a minor aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). The investigators also considered the Gallatin aquifer to be part of a larger regional Paleozoic aquifer system composed of many different Paleozoic hydrogeologic units (**pls. 4** and **5**). In the eastern Gros Ventre Range and the Salt River Range, the Gallatin Group or Limestone is classified as an aquifer and is considered part of an aquifer system composed of other Paleozoic hydrogeologic units with varying amounts of hydraulic connection (**pls. 4** and **5**). In the Wyoming Water Framework Plan, the Gallatin Group or Limestone was classified as a minor aquifer throughout Wyoming (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Gallatin Group or Limestone in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer or confining unit (Ahern and others, 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein). In the upper Colorado River Basin and adjacent areas (including Green River Basin and parts of the Overthrust Belt), Geldon (2003) classified the Gallatin Group or Limestone as a regional confining unit (see Bartos and Hallberg, 2010, Figure 5-4). In the Wind River and Bighorn Basins east of the Snake/Salt River Basin, the Gallatin Group or Limestone was classified as a confining unit (**pl. 6**) (Bartos and others, 2012, and references therein).

Permeability of the dolomite that comprises much of the Gallatin aquifer is both primary (intercrystalline) and secondary (fractures and solution openings) (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Cox (1976, Sheet 1) speculated that the formation might yield a few tens of gallons per minute to wells. Large spring discharges (100 gal/min or more) inventoried as part of this study (**pl. 3**) primarily are attributable to fractures and solution openings (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Hydrogeologic information describing the Gallatin aquifer in the Snake/Salt River Basin, including well-yield and spring-discharge measurements and other hydraulic properties, is summarized on **plate 3**.

Chemical characteristics

The chemical composition of groundwater in the Gallatin aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Gallatin aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2, E–3,** and **E–5**).

Northern Ranges
The chemical composition of the Gallatin aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as two springs. Individual constituents are listed in **appendix E–2**. The TDS concentrations (75.8 and 2,480 mg/L) indicated that waters from the springs ranged from fresh (TDS concentrations less than or equal to 999 mg/L) to slightly saline (1,000 to 2,999 mg/L) (**appendix E–2**).

Concentrations of some properties and constituents in water from the Gallatin aquifer in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. No concentrations of constituents exceeded health-based standards. Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use and State of Wyoming standards for agricultural use: TDS (exceeded SMCL limit of 500 mg/L and WDEQ Class II standard of 2,000 mg/L) and sulfate (exceeded SMCL of 250 mg/L and WDEQ Class II standard of 200 mg/L). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

Jackson Hole
The chemical composition of the Gallatin aquifer in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one well. Individual constituents are listed in **appendix E–3**. The TDS concentration (355 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for in the one sample, the quality of water from the Gallatin aquifer in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt
The chemical composition of groundwater in the Gallatin aquifer in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–5**. The TDS concentration (203 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for in the spring sample, the quality of water from the Gallatin aquifer in the OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.11 Park Shale, Meagher Limestone, and Wolsey Shale

Within the Snake/Salt River Basin, the Middle and Upper Cambrian Park Shale, Middle Cambrian Meagher Limestone, and Middle Cambrian Wolsey Shale are present only in the Yellowstone Volcanic area (**pl. 1; pl. 6**). The Park Shale and Wolsey Shale consist of green micaceous shale (Love and Christiansen, 1985, Sheet 2). The Meagher Limestone consists of blue-gray and yellow mottled hard limestone (Love and Christiansen, 1985, Sheet 2). Cox (1976, Sheet 1) speculated that wells completed in the formations probably would not yield more than a few gallons per minute. No data were located describing the physical and chemical hydrogeologic characteristics of the lithostratigraphic units in the Snake/Salt River Basin.

7.4.12 Gros Ventre aquifer and confining unit

The physical and chemical characteristics of the Gros Ventre aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Middle and Upper Cambrian Gros Ventre Formation (**pls. 4, 5,** and **6**) in the Overthrust Belt is composed of gray and tan, oolitic in part, limestone with green-gray micaceous shale in the middle of the formation (Lines and Glass, 1975; Oriel and Platt, 1980). Thickness of the Gros Ventre Formation in the Overthrust Belt ranges from about 400 to 1,300 ft (Schroeder, 1974, 1981; Lines and Glass, 1975; Oriel and Platt, 1980; Lageson, 1986).

In the Gros Ventre Range, the Gros Ventre Formation includes three members—the Park Shale, Death Canyon Limestone, and Wolsey Shale Members (Love and others, 1992; see Plate 5 under Mills, 1989; Mills and Huntoon, 1989). The Park Shale Member consists of olive-green, soft, flaky, micaceous shale with thin beds of flat-pebble limestone conglomerate; the basal part of the unit has numerous large and small algal heads. Thickness of the Park Shale Member ranges from 150 to 350 ft. The Death Canyon Limestone Member consists of blue- to dark-gray, mottled brown and tan, dense, thin-bedded, cliff-forming limestone. The middle part of the Death Canyon Limestone Member contains 30 ft of flaky green shale with abundant trilobites; locally, at the base, a distinctive bed of brown-weathering dolomite is present. Thickness of the Death Canyon Limestone Member ranges from 300 to 370 ft. The Wolsey Shale Member consists of green to gray-green, soft, highly fissile micaceous shale that is siltier near the base; the lower part of the unit is very glauconitic and interbedded with sandstone, and the glauconite weathers to a red hematite color. Thickness of the Wolsey Shale Member ranges from 100 to 130 ft. The contact between the Wolsey Shale Member and the underlying Flathead Sandstone is transitional.

The Gros Ventre Formation is classified as an aquifer or confining unit by previous investigators (**pls. 4, 5,** and **6**). The Wyoming Water Planning Program (1972, Table III-2) speculated that the Gros Ventre Formation was a probable poor aquifer in the Snake/Salt River Basin (**pls. 4, 5,** and **6**). In the Salt River Range, the Gros Ventre Formation was classified as a confining unit (**pl. 4**) (Blanchard, 1990; Blanchard and others, 1990). In the eastern Gros Ventre Range, the formation was classified as both aquifer and confining unit—the Wolsey Shale and Park Shale Members composed primarily of shale were classified as confining units and the Death Canyon Limestone Member composed primarily of limestone was classified as an aquifer (**pl. 5**) (Mills, 1989; Mills and Huntoon, 1989). In the Wyoming Water Framework Plan, the Gros Ventre Formation was classified as a minor aquifer throughout Wyoming (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**).

Investigators for previous studies of the Gros Ventre Formation in areas adjacent to the Snake/Salt River basin have classified the formation as an aquifer or confining unit (Ahern and others, 1981; Geldon, 2003; Bartos and Hallberg, 2010, and references therein) (**pls. 4** and **5**). Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as an aquitard (confining unit) in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). In the upper Colorado River Basin and adjacent areas (including Green River Basin, and parts of the Overthrust Belt), Geldon (2003) classified the Gros Ventre Formation as a regional confining unit (see Bartos and Hallberg, 2010, Figure 5-4). In the Wind River and Bighorn Basins east of the Snake/Salt River Basin, the Gros Ventre Formation was classified as a confining unit (**pl. 6**) (Bartos and others, 2012, and references therein). Because the unit consists of locally permeable zones interbedded with predominantly low-permeability lithologic units, the Gros Ventre Formation in the Snake/Salt River Basin was classified herein as a sequence of rocks that functions as both aquifer and confining unit, reflecting hydrogeologic characteristics that differ by location examined and the scale of the study.

Much of the Gros Ventre Formation consists primarily of poorly permeable rock. Permeability of the Gros Ventre Formation is attributable primarily to development of secondary permeability in the form of fractures and solution openings in limestone that composes parts of the unit (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Cox (1976, Sheet 1) speculated that the formation might yield a few tens of gallons per minute to wells. Shale within the formation has very little permeability, and the lithologic units act as confining units (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Large spring discharges (100 gal/min or more) inventoried as part of this study (**pl. 3**) are attributable to fractures and solution openings in limestone (Lines and Glass, 1975; Cox, 1976; Mills, 1989; Mills and Huntoon, 1989). Few hydrogeologic data are available describing the Gros Ventre aquifer and confining unit in the Snake/Salt River Basin, but spring-discharge measurements are summarized on **plate 3**.

Chemical characteristics

The chemical composition of groundwater in the Gros Ventre aquifer and confining unit in the Snake/Salt River Basin are described in this section of the report. Groundwater quality of the Gros

Ventre aquifer and confining unit is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendices E–2** and **E–3**).

Northern Ranges
The chemical composition of the Gros Ventre aquifer and confining unit in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water sample from as many as five springs. Summary statistics calculated for available constituents are listed in **appendix E–2**. Major ion composition in relation to TDS for springs issuing from the Gros Ventre aquifer and confining unit in the NR is shown on a trilinear diagram (**appendix F–2, diagram I**). TDS concentrations indicated that all waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2; appendix F–2, diagram I**). The TDS concentrations for the springs ranged from 86.8 to 148 mg/L, with a median of 107 mg/L. On the basis of the characteristics and constituents analyzed for, the quality of water from the Gros Ventre aquifer and confining unit in the NR was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Jackson Hole
The chemical composition of the Gros Ventre aquifer and confining unit in Jackson Hole (JH) was characterized and the quality evaluated on the basis of one environmental water sample from one spring. Individual constituents are listed in **appendix E–3**. The TDS concentration (308 mg/L) indicated that the water was fresh (TDS concentration less than or equal to 999 mg/L) (**appendix E–3**). On the basis of the characteristics and constituents analyzed for in the one sample, the quality of water from the Gros Ventre aquifer and confining unit in JH was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

Overthrust Belt
The chemical composition of groundwater in the Gros Ventre aquifer and confining unit in the Overthrust Belt (OTB) was characterized and the quality evaluated on the basis of environmental water samples from two springs. Individual constituents are listed in **appendix E–5**. The TDS concentrations (102 and 152 mg/L) indicated that the waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–5**). On the basis of the characteristics and constituents analyzed for in the spring samples, the quality of water from the Gros Ventre aquifer and confining unit in OTB was suitable for most uses. No characteristics or constituents approached or exceeded applicable USEPA or State of Wyoming domestic, agriculture, or livestock water-quality standards.

7.4.13 Flathead aquifer

The physical and chemical characteristics of the Flathead aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Flathead aquifer is composed of the Middle Cambrian Flathead Sandstone (**pls. 4, 5,** and **6**). The Flathead Sandstone consists of white to pink, tan, brown, fine-grained sandstone and some lenses of coarse-grained sandstone; the upper part includes some green, silty, micaceous shale interbeds, and the lower part is locally conglomeratic (Lines and Glass, 1975; Love and others, 1992). Much of the sandstone is quartzitic. In the Gros Ventre Range, thickness of the Flathead Sandstone ranges from 200 to 300 ft (Schroeder, 1969, 1972, 1976; Love and Love, 1978; Love and others, 1992; Love and Love, 2000; Love, 2001b; Love and Reed, 2001a). Thickness of the Flathead Sandstone in the Teton Range ranges from 150 to 240 ft (Pampeyan and others, 1967; Schroeder, 1969; Christiansen and others, 1978; Oriel and Moore, 1985; Love and others, 1992; Love and Reed, 2000; Love, 2003a).

Little information is available describing the hydrogeologic characteristics of the Flathead

Sandstone in the Snake/Salt River. Cox (1976, Sheet 1) speculated that the formation might yield a few tens of gallons per minute to wells. Because the formation was composed primarily of sandstone, Lines and Glass (1975) speculated that the Flathead Sandstone was probably a potential source of water in the Overthrust Belt.

Much of what is known about the hydrogeologic characteristics of the Flathead Sandstone is from the Green River Basin to the east and adjacent areas and elsewhere in Wyoming. Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a minor aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). In the Wyoming Water Framework Plan, the Flathead Sandstone was classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Flathead Sandstone in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern and others, 1981; Taylor and others, 1986; Lindner-Lunsford and others, 1989; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Snake/Salt River was tentatively retained herein (**pls. 4, 5,** and **6**). Few hydrogeologic data are available describing the Flathead aquifer in the Snake/Salt River, but spring-discharge measurements are summarized on **plate 3**.

Reported descriptions of permeability of the Flathead Sandstone in Wyoming vary by investigator and the geographic area examined. In the Wind River Basin and Granite Mountains area east of the Snake/Salt River Basin, Richter (1981, Table IV-1) reported that porosity and permeability is intergranular, but that secondary permeability is present along bedding-plane partings and as fractures associated with folds and faults; the investigator classified the Flathead Sandstone as a "major aquifer" in the Wind River Basin and adjacent Granite Mountains area east of the Snake/Salt River Basin. Similarly, in the Bighorn Basin east of the Absaroka Range in the Snake/Salt River Basin, previous investigators (Cooley, 1984, 1986; Doremus, 1986; Jarvis, 1986; Spencer, 1986) also reported intergranular porosity and permeability but also noted secondary permeability development along bedding-plane partings and as fractures associated with folds; all of these investigators classified the Flathead Sandstone as an aquifer. In contrast, Boner and others (1976) and Weston Engineering, Inc. (2008) noted that the Flathead Sandstone in the southern Powder River Basin in northeastern Wyoming and in the northern flank of the Laramie Mountains in south-central Wyoming was well cemented and poorly sorted with little primary (intergranular) permeability. In addition, Weston Engineering, Inc. (2008, p. II-4) also noted that bedding-plane partings may provide some permeability, but that silica cement in the formation is not readily dissolved, and that "permeability of the unit is likely to be similar to that of the underlying Precambrian rocks."

Chemical characteristics

The chemical composition of groundwater in the Flathead aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Flathead aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–2**).

Northern Ranges

The chemical composition of the Flathead aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as two hot springs (Granite Hot Springs, about 15 miles east-northeast of Hoback Junction). Individual constituents are listed in **appendix E–2**. The TDS concentrations (670 to 826 mg/L) indicated that waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2**).

Concentrations of some properties and constituents in water from hot springs issuing from the Flathead aquifer in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. One constituent (fluoride) was measured at concentrations greater than health-based standards (both samples exceeded the USEPA MCL of 4 mg/L). Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: TDS (both samples exceeded the SMCL of 500 mg/L) and fluoride (both samples exceeded the SMCL of 2 mg/L).

Concentrations of some characteristics and constituents in water from hot springs issuing from the Flathead aquifer approached or exceeded State of Wyoming standards for agricultural and livestock use in the NR. One characteristic and one constituent were measured in environmental water samples from hot springs at concentrations greater than agricultural-use standards: chloride (both samples exceeded the WDEQ Class II standard of 100 mg/L) and SAR (1 of 2 samples exceeded the WDEQ Class II standard of 8). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.

7.5 Precambrian basal confining unit

The physical and chemical characteristics of the Flathead aquifer in the Snake/Salt River Basin are described in this section of the report.

Physical characteristics

The Flathead aquifer is composed of the Middle Cambrian Flathead Sandstone (**pls. 4, 5,** and **6**). The Flathead Sandstone consists of white to pink, tan, brown, fine-grained sandstone and some lenses of coarse-grained sandstone; the upper part includes some green, silty, micaceous shale interbeds, and the lower part is locally conglomeratic (Lines and Glass, 1975; Love and others, 1992). Much of the sandstone is quartzitic. In the Gros Ventre Range, thickness of the Flathead Sandstone ranges from 200 to 300 ft (Schroeder, 1969, 1972, 1976; Love and Love, 1978; Love and others, 1992; Love and Love, 2000; Love, 2001b; Love and Reed, 2001a). Thickness of the Flathead Sandstone in the Teton Range ranges from 150 to 240 ft (Pampeyan and others, 1967; Schroeder, 1969; Christiansen and others, 1978; Oriel and Moore, 1985; Love and others, 1992; Love and Reed, 2000; Love, 2003a).

Little information is available describing the hydrogeologic characteristics of the Flathead Sandstone in the Snake/Salt River. Cox (1976, Sheet 1) speculated that the formation might yield a few tens of gallons per minute to wells. Because the formation was composed primarily of sandstone, Lines and Glass (1975) speculated that the Flathead Sandstone was probably a potential source of water in the Overthrust Belt.

Much of what is known about the hydrogeologic characteristics of the Flathead Sandstone is from the Green River Basin to the east and adjacent areas and elsewhere in Wyoming. Ahern and others (1981, Figure II-7, and Table IV-1) classified the formation as a minor aquifer in the Overthrust Belt and adjacent Green River Basin (**pls. 4** and **5**). In the Wyoming Water Framework Plan, the Flathead Sandstone was classified as a major aquifer (WWC Engineering and others, 2007, Figure 4-9) (**pls. 4, 5,** and **6**). Previous studies of the Flathead Sandstone in the adjacent Green River Basin and surrounding areas have classified the formation as an aquifer (Ahern and others, 1981; Taylor and others, 1986; Lindner-Lunsford and others, 1989; Geldon, 2003; Bartos and Hallberg, 2010, and references therein); classification of the formation as an aquifer in the Snake/Salt River was tentatively retained herein (**pls. 4, 5,** and **6**). Few hydrogeologic data are available describing the Flathead aquifer in the Snake/Salt River, but spring-discharge measurements are summarized on **pl. 3**.

Reported descriptions of permeability of the Flathead Sandstone in Wyoming vary by investigator and the geographic area examined. In the Wind River Basin and Granite Mountains area east of the Snake/Salt River Basin, Richter (1981, Table IV-1) reported that porosity and permeability is intergranular, but that secondary permeability is present along bedding-plane partings and as fractures associated with folds and faults; the investigator classified the Flathead Sandstone as a "major aquifer" in the Wind River Basin and adjacent Granite Mountains area east of the Snake/

Salt River Basin. Similarly, in the Bighorn Basin east of the Absaroka Range in the Snake/Salt River Basin, previous investigators (Cooley, 1984, 1986; Doremus, 1986; Jarvis, 1986; Spencer, 1986) also reported intergranular porosity and permeability but also noted secondary permeability development along bedding-plane partings and as fractures associated with folds; all of these investigators classified the Flathead Sandstone as an aquifer. In contrast, Boner and others (1976) and Weston Engineering, Inc. (2008) noted that the Flathead Sandstone in the southern Powder River Basin in northeastern Wyoming and in the northern flank of the Laramie Mountains in south-central Wyoming was well cemented and poorly sorted with little primary (intergranular) permeability. In addition, Weston Engineering, Inc. (2008, p. II-4) also noted that bedding-plane partings may provide some permeability, but that silica cement in the formation is not readily dissolved, and that "permeability of the unit is likely to be similar to that of the underlying Precambrian rocks."

Chemical characteristics

The chemical composition of groundwater in the Flathead aquifer in the Snake/Salt River Basin is described in this section of the report. Groundwater quality of the Flathead aquifer is described in terms of a water's suitability for domestic, irrigation, and livestock use, on the basis of USEPA and WDEQ standards (**table 5-2**), and groundwater-quality sample summary statistics tabulated by hydrogeologic unit as quantile values (**appendix E–2**).

Northern Ranges

The chemical composition of the Flathead aquifer in the Northern Ranges (NR) was characterized and the quality evaluated on the basis of environmental water samples from as many as two hot springs (Granite Hot Springs, about 15 miles east-northeast of Hoback Junction). Individual constituents are listed in **appendix E–2**. The TDS concentrations (670 to 826 mg/L) indicated that waters were fresh (TDS concentrations less than or equal to 999 mg/L) (**appendix E–2**).

Concentrations of some properties and constituents in water from hot springs issuing from the Flathead aquifer in the NR approached or exceeded applicable USEPA or State of Wyoming water-quality standards and could limit suitability for some uses. One constituent (fluoride) was measured at concentrations greater than health-based standards (both samples exceeded the USEPA MCL of 4 mg/L). Concentrations of one characteristic and one constituent exceeded USEPA aesthetic standards for domestic use: TDS (both samples exceeded the SMCL of 500 mg/L) and fluoride (both samples exceeded the SMCL of 2 mg/L).

Concentrations of some characteristics and constituents in water from hot springs issuing from the Flathead aquifer approached or exceeded State of Wyoming standards for agricultural and livestock use in the NR. One characteristic and one constituent were measured in environmental water samples from hot springs at concentrations greater than agricultural-use standards: chloride (both samples exceeded the WDEQ Class II standard of 100 mg/L) and SAR (1 of 2 samples exceeded the WDEQ Class II standard of 8). No characteristics or constituents approached or exceeded applicable State of Wyoming livestock water-quality standards.